APR 2 1924

VOL. XVII MARCH, 1924 No. 3

SOIL SCIENCE

FOUNDED BY

RUTGERS COLLEGE

NEW BRUNSWICK, N. J.

JACOB G. LIPMAN, Editor-in-Chief

Assistant Editors

CARL R. WOODWARD

CHARLES A. DOEHLERT

IN CONSULTATION WITH

DR. F. J. ALWAY
University of Minnesota, St. Paul, Minn.
PROF. C. BARTHEL
Centralanstalten för Försöksväsendet på Jordbruksområdet, Stockholm, Sweden
PROF. A. W. BLAIR
Rutgers College, New Brunswick, N. J.
DR. P. E. BROWN
Iowa State College of Agriculture, Ames, Iowa
ALBERT BRUNO
Ministry of Agriculture, Paris, France
DIRECTOR H. R. CHRISTENSEN
Statens Planteavls-Laboratorium, Lyngby, Denmark
DR. H. J. CONN
New York State Experiment Station, Geneva, N. Y.
PROF. DR. H. VON FEILITZEN
Centralanstalten för Försöksväsendet på Jordbruksområdet, Stockholm, Sweden
DR. E. B. FRED
University of Wisconsin, Madison, Wis.
DR. J. E. GREAVES
Utah Agricultural College, Logan, Utah
DIRECTOR ACH. GREGOIRE
Agricultural Experiment Station, Gembloux, Belgium
DR. R. GREIG-SMITH
Linnean Society, Sydney, New South Wales
DR. B. L. HARTWELL
Rhode Island Experimental Station, Kingston, R. I.
DR. D. J. HISSINK,
Agricultural Experiment Station, Groningen, Holland
DR. C. B. LIPMAN
University of California, Berkeley, Calif.
DR. BURTON E. LIVINGSTON
Johns Hopkins University, Baltimore, Md.
DR. F. LÖHNIS
U. S. Department of Agriculture, Washington, D. C.
DR. T. L. LYON
Cornell University, Ithaca, N. Y.
DR. M. M. MCCOOL
Michigan Agricultural College, East Lansing, Mich.
DR. W. H. MACINTIRE
Tennessee Experiment Station, Knoxville, Tenn.
DR. E. A. MITSCHERLICH
University of Königsberg, Prussia
PROF. C. A. MOOERS
Tennessee Experiment Station, Knoxville, Tenn.
DR. THEO. REMY
Institut für Boden- und Pflanzenbaulehre, Bonn a. Rh.
PROF. G. ROSSI
Royal Agricultural High School in Portici, Naples, Italy
DR. E. J. RUSSELL
Rothamsted Experiment Station, Harpenden, England
DR. O. SCHREINER
U. S. Department of Agriculture, Washington, D. C.
DR. ALEXIUS A. F. DE 'SIGMOND
Royal Joseph University of Technicology, Budapest, Hungary
PROF. CHAS. E. THORNE
Ohio Experiment Station, Wooster, Ohio
PROF. N. M. TULAIKOV
Agricultural Experiment Station, Saratov, Russia

PUBLISHED MONTHLY BY

WILLIAMS & WILKINS COMPANY

BALTIMORE, MD., U. S. A.

Entered as second-class matter May 12, 1919, at the post office at Baltimore, Maryland, under the act of March 3, 1879

Copyright 1924, by Williams & Wilkins Company

Price per volume, net post paid { $5.00, United States, Canada, Mexico, Cuba
$5.50, other countries

Made in United States of America

SOIL SCIENCE

Contents for March, 1924

C. O. Swanson, P. L. Gainey, and W. L. Latshaw. The Calcium Content of Soil in Relation to Absolute Reaction 181

Norman Ashwell Clark and Emery M. Roller. "Auximones" and the Growth of the Green Plant 193

J. A. Viljoen and E. B. Fred. The Effect of Different Kinds of Wood and of Wood Pulp Cellulose on Plant Growth 199

F. L. Duley. Easily Soluble Calcium of the Soil in Relation to Acidity and Returns from Liming 213

F. W. Parker. Carbon Dioxide Production of Plant Roots as a Factor in the Feeding Power of Plants 229

F. W. Morse. The Loss of Calcium Carbonate in Drainage Water as Affected by Different Chemical Fertilizers 249

Carleton P. Jones. Adsorption and Absorption of Bases by Soils 255

THE WILLIAMS & WILKINS Company – BALTIMORE

Publishers of Scientific Journals and Booksellers

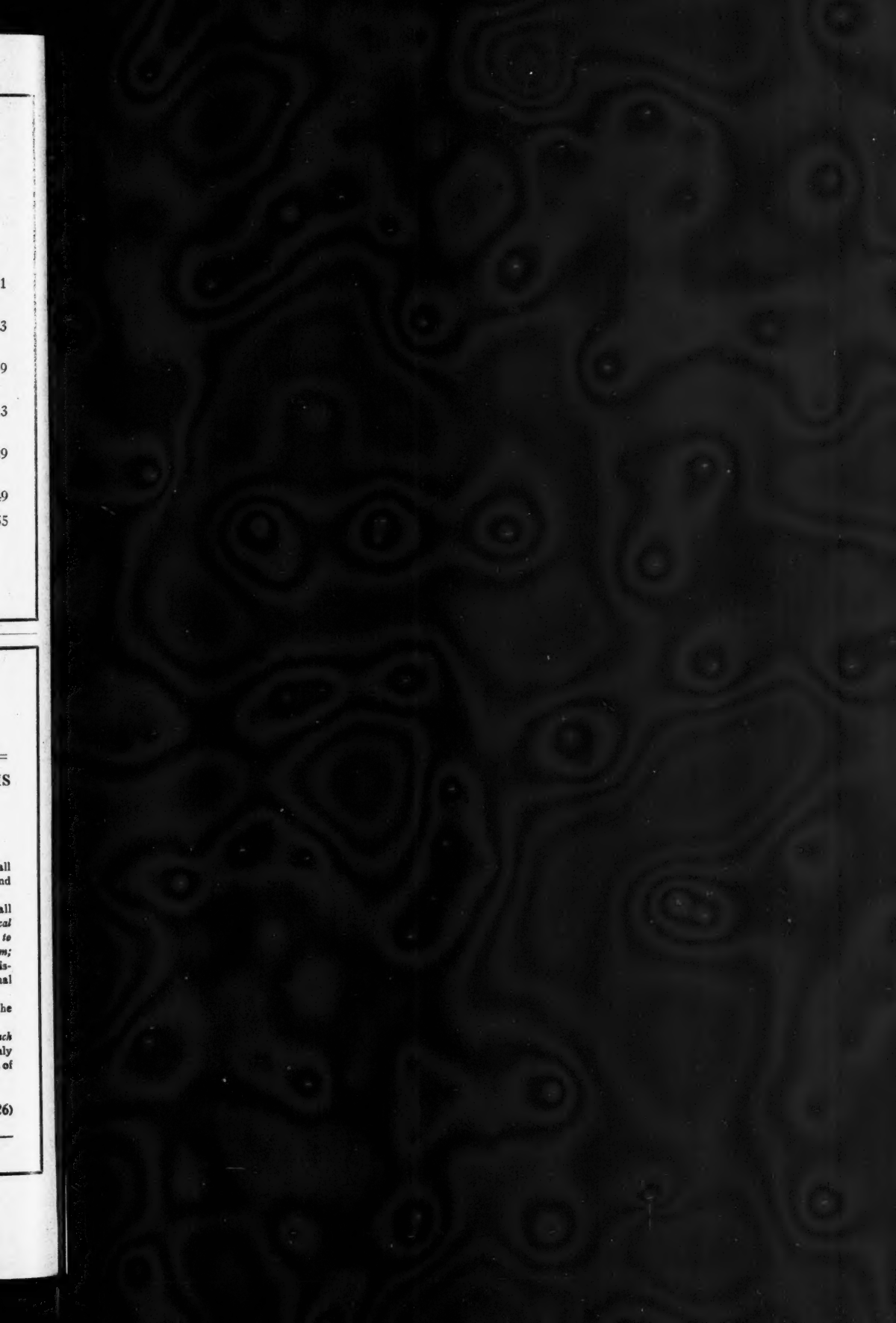
MOUNT ROYAL and GUILFORD AVENUES, BALTIMORE (Maryland, U. S. A.).

"SCIENTIA" **INTERNATIONAL REVIEW OF SCIENTIFIC SYNTHESIS**
Published every month (each number containing 100 to 120 pages)
Editor: EUGENIO RIGNANO

IS THE ONLY REVIEW the contributors to which are really international.
IS THE ONLY REVIEW that has a really world-wide circulation.
IS THE ONLY REVIEW of scientific synthesis and unification that deals with the fundamental questions of all sciences: the history of the sciences, mathematics, astronomy, geology, physics, chemistry, biology, psychology and sociology.
IS THE ONLY REVIEW that by means of enquiries among the most eminent scientists and authors of all countries (*On the philosophical principles of the various sciences; On the most fundamental astronomical and physical questions of current interest, and in particular on relativity; On the contribution that the different countries have given to the development of various branches of knowledge; On the more important biological questions, and in particular on vitalism; On the social question; On the great international questions raised by the World War*), studies all the main problems discussed in intellectual circles all over the world, and represents at the same time the first attempt at an international organization of philosophical and scientific progress.
IS THE ONLY REVIEW that among its contributors can boast of the most illustrious men of science in the whole world. A list of more than 350 of these is given in each number.
The articles are published in the language of their authors, and every number has *a supplement containing the French translation of all the articles that are not French.* The review is thus completely accessible to those who know only French. (*Write for a gratis specimen number* to the General Secretary of "Scientia," Milan, sending 1 sh. in stamps of your country, merely to cover postal expenses).

SUBSCRIPTION: Sh. 40; $10, post free **OFFICE: Via A. Bertani, 14 - Milan (26)**

General Secretary, Dr. Paolo Bonetti



THE CALCIUM CONTENT OF SOIL IN RELATION TO ABSOLUTE REACTION[1]

C. O. SWANSON, P. L. GAINEY, AND W. L. LATSHAW

Kansas Agricultural Experiment Station

Received for publication November 7, 1923

INTRODUCTION

The importance of reaction in soil investigations is emphasized by the long lists of references given by Fisher (3) and McIntire (10) as well as others. The cause and nature of soil acidity have received a great deal of study (5, 6, 16). Recent developments in physical chemistry have served to clarify the terms acid, neutral, and alkaline. In an acid solution the hydrogen ions are in excess, in an alkaline solution the hydroxyl ions are in excess, while in an absolutely neutral solution the concentrations of these two ions are equal. Since water contains both these ions it follows that a water suspension or a water extract of soil always contains both hydrogen ions and hydroxyl ions and acidity or alkalinity is determined by the one in excess. The more nearly equal the concentrations of these two ions, the more nearly neutral is the soil reaction. This is the meaning of soil acidity as used in this discussion; however, it is recognized that the term may have a much wider application (9).

The fundamental cause of an acid condition of soil is the removal of bases by the process of weathering. A suspension of finely gound orthoclase in water gives an alkaline reaction which may be written:

$$KAlSi_3O_8 + HOH = KOH + KAlSi_3O_8$$

Qualitatively, the same reaction would take place regardless of the base present in the original mineral. Under humid climatic conditions the bases are converted into carbonates, in which form they are leached away and the acid-alumino-silicates accumulate in the soil. The reaction is not as simple as indicated by this equation but it serves to illustrate the process. Organic matter is an indirect cause of soil acidity in that its decay promotes the decomposition of those minerals which go to make up the soil.

Under present climatic conditions calcium is leached from the surface soil much more rapidly than many other bases (7). That certain bases are not leached from the soil as rapidly as others is illustrated by the following example (14). In twenty-six Kansas soils formed from limestone, the average content of calcium in the surface soil was found to be 0.75 per cent and that of potassium, 1.80 per cent. The average content of calcium in three hundred forty-five limestones was found by Clarke (2) to be 30.45 per cent and that of potassium 0.27 per cent. The average content of potassium in Kansas soils is about three times as great as that of calcium (14, 15). Potassium is evidently held more firmly by the alumino-silicates than calcium. When a neutral salt like potassium chloride is added to a soil containing alumino-silicates, the potassium is strongly absorbed (11) and bases like calcium are set free (17), and thus lost by leaching. Lyon and Bizzel (8) have reported a loss of

[1] Contribution No. 104, Department of Chemistry and No. 58, Department of Bacteriology, Kansas Agricultural Experiment Station.

calcium equivalent to 730 pounds of calcium carbonate from the unlimed and seven hundred forty-three from the limed soil during one year.

From the foregoing discussion it would seem that the calcium content of the soil might bear some relation to soil reaction and since it has been well established that soil reaction is a dominant factor in the growth of many forms of plant life it was thought worth while to study the relation between the calcium content of soil and the absolute reaction. The soils used by Gainey (4) in investigating the relationship between soil reaction and Azotobacter were available and since the absolute reaction as well as their Azotobacter content were already known they were used in this study.[2]

METHODS

Since it has been established that the calcium soluble in normal hydrochloric acid bears a closer relation to reaction than the total calcium (15), it was decided to determine calcium by the following method:

Twenty-five grams of soil were placed in 500-cc. wide-mouth, rubber-stoppered bottles and 250 cc. normal HCl added, after which the bottles were shaken on a shaking machine for several hours. After settling, aliquot portions were removed with a pipette and the calcium determined in the usual way. Preliminary trials indicated that filtering and washing the acid insoluble residue did not add to the accuracy.

For convenience in study, the results obtained are divided into three groups. Group 1 includes all soils taken in the vicinity of Manhattan, Riley County, Kansas; group 2, all soils from other counties in Kansas; group 3, all soils obtained from experiment stations in other states. The figures for the hydrogen-ion concentration (electrometric), as well as the symbols + and − indicating presence or absence of Azotobacter, are the same as those reported by Gainey (4).

SOILS FROM RILEY COUNTY

For the soils in group 1, the type was known and in studying the results it soon became evident that soil type was one of the factors to be considered in correlating the amount of calcium with the absolute reaction. As the number of soils for each type was small, it was thought best to class the soils by series. The results obtained on soils in group 1 are found in table 1.

The figures under each of the soil series are arranged according to increasing numerical values of pH. It is at once apparent that there is a general correlation between the pH values and the percentages of calcium; in a general way as the percent of calcium increases, the alkalinity also increases, however, there are some exceptions.

[2] Not all of the soils used in the former study were included, partly because some were duplicates and partly because in some instances sufficient amount of soil was not available for the chemical determination.

TABLE 1

Relation between absolute reaction, calcium soluble in normal hydrochloric acid, and Azotobacter content of soils of group 1, Riley county, Kansas

SOIL NO.	AZOTOBACTER	pH VALUES	PERCENTAGE OF Ca
Marshall clay loam			
49	−	5.03	0.17
21	−	5.05	0.20
23	−	5.10	0.18
22	−	5.27	0.20
Marshall silt loam			
69	−	5.19	0.20
50	−	5.32	0.19
66	−	5.81	0.29
65	−	5.94	0.21
41	+	5.98	0.29
70	+	6.93	0.33
29*	+	7.27	0.56
Oswego silt loam			
24	−	4.90	0.24
60	−	5.73	0.30
68	+	6.05	0.25
57	+	7.30	0.50
Wabash silt loam			
67	−	5.32	0.32
61*	−	5.51	0.29
Wabash silt loam—Cont.			
38*	+	5.59	0.31
71	+	5.61	0.40
28*	+	5.81	0.19
27*	+	5.88	0.33
39*	+	6.05	0.34
25†	+	6.45	0.44
42	+	7.05	0.39
Osage silt loam			
77	−	5.34	0.24
76	−	5.63	0.26
73	−	5.88	0.44
88	+	6.88	0.41
90	+	7.06	0.54
74	+	7.25	0.61
75	+	7.30	0.63
86	+	7.60	0.43
85‡	+	7.62	1.11
89‡	+	7.76	0.97
Summit silt loam (colluvial)			
58§	−	5.46	0.17
32	−	5.85	0.26
54	+	6.18	0.27
Summit silt loam (colluvial)—Cont.			
64	+	6.35	0.35
40	+	6.72	0.42
34	+	6.74	0.30
56‖	+	7.18	0.33
63**	+	7.43	0.55
59	+	7.49	0.80
55‖	+	7.50	0.44
87††	+	7.59	4.45
83	+	7.72	5.59
Laurel fine sandy loam			
46	−	6.03	0.15
84	+	7.47	1.38
82	+	7.60	7.92
81	+	7.77	0.74
31‡‡	+	7.71	0.93
Laurel very fine sandy loam			
48	+	6.52	0.22
45	+	7.45	0.53
47	+	7.52	0.68
44	+	7.71	0.46
80	+	7.84	0.90
79‖‖	+	8.48	0.38

* Silty clay loam.
† Silty clay.
‡ Fine sandy loam.
§ Stony loam.
‖ Loam (colluvial).
** Silt (colluvial).
†† Stony loam (creek bank).
‡‡ Silt loam.
‖‖ Medium sand.

The coefficients of correlation between pH numbers and percentages of calcium were calculated by the usual formula for each soil series except the Laurel. The results obtained were:

Marshall series..... 0.899 ± 0.0389
Oswego series..... 0.912 ± 0.0663
Wabash series..... 1.000 ± 1.1135
Osage series..... 0.805 ± 0.0338
Summit series..... 0.557 ± 0.1290

This correlation is good except for the Summit series. The figures in table 1 show that the last two soils of this series had about ten times as much calcium as the average of the others in the series, while the increase in pH was comparatively very small. When calcium is present in the form of a carbonate the amount, beyond a certain limit, has very little influence on the pH. The coefficient of correlation was recalculated for the Summit series leaving out the last two soils. The coefficient of correlation thus obtained was 0.781 ± 0.0675. The lack of correlation in the Laurel series is probably due to the presence of calcium in the form of carbonate even when only small amounts are found, and also the influence of sand.

SOILS FROM OTHER COUNTIES OF KANSAS

The type of soil of those samples obtained from different counties in Kansas was not known, only a very general description being available. Meager as this information was it helps to explain the results in some cases. In studying the pH values and percentages of calcium it soon became evident that the results from the eastern part of the state could not be compared directly with those from the western part of the state, due probably to the more frequent occurrence of carbonate in the soils of the western part, even when the content of calcium was comparatively small. For this reason the data were arranged separately for each county according to the increase in pH values; also the data from the counties in the eastern and central parts of the state were placed in one sub-group, and the data from the counties in the extreme western part of the state were placed in another sub-group.

The data as arranged are given in tables 2 and 3. In each sub-group the counties are arranged in alphabetical order.

In using the hydrogen electrode on soils the analytical error is probably about 10 millivolts. This means that differences of 0.15 pH or possibly 0.2 pH are not significant. This is a large figure when compared with results obtained with the hydrogen electrode on pure solutions. Several investigators have found that it is practically impossible to obtain very close duplicates on pH values on soils. The reasons for this do not seem to be known. The analytical error in the calcium determination can be considered about one milligram.

If the data presented in tables 2 and 3 are studied with regard to these considerations, it will be found that within each county there is a close relation between the pH numbers and the percents of calcium; the higher the calcium the higher the pH number. This statement holds true for all the counties and all the soils with the following exceptions:

The difference in calcium content of soils 176 and 177, Anderson County, is not significant while the difference in pH is large. This is explained by the fact that soil 176 was sandy while 177 was a silt soil. The same explanation probably holds true for soil 166 from Cloud County and 175 from Franklin County. Soil 240 from Pawnee County, with the highest pH value and

TABLE 2

Relation between absolute reaction, calcium soluble in normal hydrochloric acid, and Azotobacter content of soils in counties of eastern and central Kansas

SOIL NO.	AZOTOBACTER	pH VALUES	PERCENTAGE OF Ca
Anderson			
178	−	5.30	0.20
177	−	5.37	0.30
176	+	6.35	0.31
Atchison			
191	−	5.32	0.30
190	−	5.34	0.28
189	−	5.52	0.33
188	+	5.52	0.37
Bourbon			
229	+	7.60	0.72
Chase			
196	−	4.90	0.31
195	−	5.69	0.29
197	+	7.57	0.43
Chautauqua			
237	−	5.02	0.21
244	−	5.22	0.44
236	−	5.30	0.34
Cloud			
164	−	5.41	0.16
165	−	5.54	0.18
166	−	5.71	0.17
163	+	5.98	0.30
Coffey			
252	−	5.37	0.29
251	−	6.10	0.39
Doniphan			
206	−	5.32	0.19
205	+	6.02	0.22
207	+	7.94	0.84
Douglas			
249	−	5.12	0.22
247	−	5.37	0.28
248	−	5.47	0.24
246	−	5.90	0.25
Elk			
242	−	5.90	0.25
Franklin			
169	+	5.10	0.23
168	−	5.17	0.32
175	−	5.29	0.23
174	−	5.85	0.32
Greenwood			
254	−	4.68	0.25
210	−	5.05	0.16
211	−	5.10	0.23
217	+	5.15	0.27
212	−	5.39	0.23
209	−	5.53	0.33
233	+	7.47	0.54
Jackson			
277	−	5.10	0.17
276	−	5.27	0.20
Jewell			
194	+	6.15	0.28
193	+	6.84	0.41
219	−	7.25	0.46
218	+	7.28	0.33
Lyon			
263	−	4.93	0.30
198	−	5.49	0.36
199	+	6.07	0.53
Marshall			
181	+	6.10	0.24
182	−	6.52	0.32
184	+	6.77	0.39
183	+	7.37	0.59
McPherson			
228	−	5.20	0.21
227	−	5.66	0.26
225	+	5.91	0.33
226	+	7.13	0.38
Morris			
238	−	5.54	0.25
Nemaha			
180	−	5.47	0.37
179	−	5.76	0.36
Osborne			
201	−	5.98	0.29
230	+	6.98	0.47
200	+	8.28	1.12
Pottawatomie			
220	+	6.34	0.30
Pratt			
261	−	5.81	0.23
273	−	6.42	0.16
262	−	7.23	0.32
Washington			
204	−	5.10	0.17
Wilson			
172	−	5.02	0.16
171	+	5.15	0.18
192	−	5.22	0.26
170	+	5.93	0.33
Woodson			
271	−	5.41	0.16
Wyandotte			
185	−	5.44	0.22
167	+	6.25	0.27
187	+	6.69	0.38
186	+	7.72	0.54

lowest calcium content, was a sand from a sand dune. Soil 195, Chase County, has less calcium than soil 196 although it has a larger pH number. No explanation is available. This same statement applies to soil 244, Chautaqua County; soil 210 from Greenwood County; soil 243 Meade County; soil 179, Nemaha County; soil 273, Pratt County; and soil 214, Rawlins County. The high pH value of soil 218 from Jewell County, the calcium content of which is less than that of soils with lower pH values is probably due to the fact that soil 218 was from a second creek bottom and the calcium was possibly present in a more soluble form.

TABLE 3

Relation between absolute reaction, calcium soluble in normal hydrochloric acid, and Azotobacter content of soils in counties of western Kansas

SOIL NO.	AZOTOBACTER	pH VALUES	PERCENTAGE OF Ca
Finney			
274	+	6.96	0.19
275	+	8.06	1.26
Ford			
223	+	6.63	0.32
221	+	6.66	0.28
222	+	6.69	0.25
224	+	7.52	0.35
Hodgeman			
230	+	6.51	0.37
264	+	7.52	0.64
278	+	7.99	1.04
Kearney			
203	+	7.25	0.35
202	+	8.19	0.56
231	+	8.25	0.65
Logan			
259	+	6.49	0.34
Meade			
241	+	6.18	0.27
235	+	6.66	0.38
243	−	6.96	0.21
234	+	8.15	1.01
Pawnee			
239	+	6.08	0.21
173	+	6.08	0.23
253	+	6.25	0.57
240	+	7.03	0.12
Rawlins			
215	+	7.28	0.36
216	+	7.40	0.30
214	+	7.98	0.82
213	+	8.30	0.66
Rush			
208	+	7.60	0.57
Thomas			
260	−	7.48	0.40
Wichita			
256	−	6.35	0.30
255	+	7.79	0.45

These exceptions are few when the total number of soils involved are considered, and it shows that as a rule the higher the calcium content the higher the pH value. A smaller amount of calcium, however, is more effective in raising the pH value in a sandy soil than in a clay or silt soil. The calcium may be in a condition of greater solubility in a sandy soil, or a larger amount of calcium is required to balance the acid properties of the alumino-silicates in a clay or silt soil.

The pH value on soils from the drier portion of the state is higher for the same range of calcium than on the soils from the more humid sections. In

the eastern part of the state calcium is not present in the form of carbonate unless the amount is large. In the western part calcium may be present in the form of carbonate even though the amount present is very small. This means that climate as well as soil type is a factor which must be considered in correlating the calcium content of the soil with the pH value. The coefficient of correlation between the pH value and the calcium content was found to be 0.747 ± 0.013 for the soils from the more humid part of the state and 0.745 ± 0.0372 for the soils from the drier part of the state. This is a good correlation when the variations in the range of soil types are considered.

SOILS FROM OTHER STATES

The data obtained on soils from other experiment stations are presented in tables 4, 5 and 6. In table 4 are grouped those soils which are from the non-glaciated area, and in table 5 those from the glaciated area of central and eastern states. In table 6 are presented the data obtained on the soils from California and Oregon. A number of the soils here reported are known to have been limed more or less recently. The quantity of lime added as well as the period elapsing since lime was applied are undoubtedly factors of importance in determining the influence of such treatment upon the absolute reaction.

These soils represent a variety of climatic conditions. As a rule the soils from the eastern and southeastern states have a much lower calcium content than the soils from the central states. With a few exceptions the soils from the limed plots have a higher calcium content than those from the unlimed plots in the same state. As a general rule the high pH values are found in the soils having the higher calcium content when comparisons are made with soils from the same state. The following soils are exceptions to this general rule; 306, California; 360, Georgia; 357, Illinois; 359, Indiana; 327, Iowa; 318, North Carolina; 323, 322, and 321, New Jersey; 303, Michigan; and 339, Oregon. Two soils gave notably high pH values considering the low calcium content. These are soil 324 from Iowa and soil 303, from Michigan. Both these soils were classed as sandy. There are a few other minor exceptions but they fall within the limits of the analytical error.

Most of the soils presented in tble 4 have a calcium content of less than 0.15 per cent and a pH value less than 6.00. On the other hand, most of the soils presented in table 5 have a calcium content of more than 0.15 per cent and pH values above 6.00.

The coefficient of correlation between the pH values and the percentages of calcium was found to be as follows:

Eastern and southern soils	0.4625 ± 0.0054
Central and eastern soils	0.714 ± 0.0069
Western soils	0.317 ± 0.1060

TABLE 4

Relation between absolute reaction, calcium soluble in normal hydrochloric acid, and Azotobacter content of soils in southeastern United States

SOIL NO.	LIMED	AZOTOBACTER	pH VALUES	PERCENTAGE OF Ca
Alabama				
342	0	−	4.44	0.036
344	0	−	5.05	0.046
346	+	−	5.51	0.054
345	+	−	5.66	0.078
343	0	−	5.83	0.064
Arkansas				
335	0	−	5.05	0.100
336	0	−	5.58	0.076
334	0	+	6.96	0.086
Georgia				
362	0	−	5.24	0.056
361	+	−	6.05	0.700
360	+	−	6.69	0.280
Kentucky				
411	0	−	4.82	0.060
407	0	−	4.82	0.090
409	0	−	5.19	0.090
408	+	−	6.12	0.150
412	+	−	6.62	0.160
Maryland				
392	0	−	4.48	0.050
393	0	−	4.51	0.070
389	0	−	4.70	0.070
394	+	−	6.18	0.120
391	+	−	6.77	0.160
Mississippi				
348	0	−	4.21	0.058
347	0	+	6.17	0.270
349	0	+	6.76	0.470
North Carolina				
379	0	−	3.73	0.032
417	0	−	4.66	0.040
415	0	−	4.81	0.040
378	0	−	4.90	0.036
380	0	−	4.93	0.060
414	+	−	4.97	0.050
North Carolina—Cont.				
377	0	−	4.98	0.120
316	0	−	5.00	0.048
318	+	−	6.01	0.048
416	+	−	6.07	0.120
317	+	−	6.78	0.110
*Rhode Island**				
400	+	−	4.31	0.040
397	0	−	5.30	0.060
396	+	−	5.64	0.090
399	0	−	5.88	0.100
South Carolina				
441	0	−	4.90	0.050
438	0	+	4.98	0.050
442	+	−	5.15	0.050
443	+	−	5.34	0.050
440	+	+	7.84	0.180
439	0	+	8.14	0.270
Tennessee				
422	0	+	4.53	0.080
420	0	−	4.59	0.080
418	0	+	4.68	0.080
421	+	+	5.42	0.130
423	+	+	5.68	0.120
419	+	+	5.69	0.150
Virginia				
404	0	−	4.70	0.080
405	0	−	4.75	0.100
401	+	+	6.15	0.140
402	+	+	7.03	0.200
403	+	+	7.30	0.690
West Virginia				
428	0	−	3.99	0.040
426	0	−	4.02	0.040
424	0	−	4.09	0.060
425	+	−	4.66	0.080
427	+	−	4.90	0.080
429	+	−	5.51	0.090

* Classed with this group because of soil type.

TABLE 5

Relation between absolute reaction, calcium soluble in normal hydrochloric acid, and Azotobacter content of soils in eastern and central United States

SOIL NO.	LIMED	AZOTOBACTER	pH VALUES	PERCENTAGE OF Ca
Illinois				
355	0	−	4.19	0.069
356	0	−	4.70	0.220
353	0	−	5.00	0.190
357	+	−	5.73	0.460
354	+	+	6.51	0.240
352	+	+	7.20	0.400
Indiana				
430	0	−	4.58	0.070
359	+	−	4.93	0.270
431	+	+	5.03	0.150
Iowa				
325	0	−	4.78	0.200
326	0	−	4.83	0.250
327	0	+	4.93	0.600
328	0	−	5.88	0.240
324	0	+	7.11	0.270
Michigan				
305	0	−	5.69	0.220
301	0	−	5.76	0.120
302	0	+	6.64	0.250
303	0	−	7.38	0.140
Missouri				
265	0	−	4.36	0.130
266	0	−	4.97	0.190
267	+	+	7.10	0.420
New Jersey				
371	0	−	4.70	0.099
320	0	−	4.80	0.150
323	0	−	4.90	0.260
372	+	−	5.37	0.140
374	+	−	6.44	0.160
321	+	−	6.52	0.290
319	+	−	6.71	0.240
322	+	−	6.93	0.160
New York				
436	0	−	4.98	0.120
333	0	−	5.47	0.120
435	+	−	6.23	0.190
332	+	−	6.23	0.210
437	+	+	6.72	0.190
433	+	−	6.78	0.190
331	+	+	6.79	0.180
330	+	+	6.84	0.180
434	+	+	6.84	0.190
329	+	+	7.20	0.240
432	+	+	7.30	0.250
Massachusetts				
388	0	−	4.10	0.040
387	0	−	4.10	0.050
386	+	−	5.24	0.070
385	+	−	5.31	0.100
384	+	−	6.27	0.200
383	+	−	6.29	0.170
Ohio				
313	+	−	5.05	0.076
314	0	−	6.03	0.170
315	0	−	6.07	0.150
367	+	−	6.18	0.150
366	+	+	6.84	0.250
311	+	−	7.01	0.230
369	0	+	7.05	0.490
312	+	−	7.33	0.260
370	0	+	7.45	0.430
368	0	+	7.48	0.390
Pennsylvania				
449	0	−	4.24	0.040
446	0	−	5.07	0.110
445	0	−	5.59	0.130
444	0	+	7.20	0.360
448	+	+	8.25	1.210
447	+	+	8.41	1.200

Only one group shows good correlation. It was thought that liming might be the cause of this lack of correlation, accordingly, the coefficients of correlation of the unlimed soils were calculated and found to be as follows:

Eastern and southern soils..... $0.381 + 0.0137$
Central and eastern soils..... $0.525 + 0.0082$

Evidently, liming is not the cause of the lack of correlation.

TABLE 6

Relation between absolute reaction, calcium soluble in normal hydrochloric acid, and Azotobacter content of soils of California and Oregon

SOIL NO.	LIMED	AZOTOBACTER	pH VALUES	PERCENTAGE OF Ca	SOIL NO.	LIMED	AZOTOBACTER	pH VALUES	PERCENTAGE OF Ca
California					*Oregon*				
307	0	−	5.49	0.18	339	0	−	5.24	0.22
306	0	+	5.61	0.41	337	0	−	5.27	0.16
308	0	−	5.81	0.30	338	0	−	5.39	0.35
310	0	+	7.08	0.34	341	0	−	5.66	0.48
					340	0	−	5.93	0.62

SUMMARY AND CONCLUSION

A large number of soils obtained from the vicinity of Manhattan, Riley County, Kansas and also from various counties in the state and from different experiment stations of the United States were analyzed for calcium soluble in cold normal hydrochloric acid. The growth of Azotobacter and the pH values had been previously determined on these soils. There exists a close correlation between the calcium content and the pH value of soils of similar physical texture collected under similar climatic conditions.

REFERENCES

(1) CAMERON, F. K., AND BELL, JAMES M. 1905 The mineral constituents of the soil solution. U. S. Dept. of Agr. Bur. Soils Bul. 30.
(2) CLARKE, F. W. 1916 The data of geochemistry. U. S. Geol. Sur. Bul. 616, p. 821.
(3) FISHER, E. A. 1921 Studies on soil reaction. *In* Jour. Agr. Sci., v. 11, p. 19–65.
(4) GAINEY, P. L. 1923 The influence of absolute reaction of a soil upon its azotobacter flora and nitrogen fixing ability. *In* Jour. Agr. Res., v. 24, no. 11, p. 907–938.
(5) HARRIS, J. E. 1914 Some adsorption phenomena in soils and kaolin. *In* Jour. Phys. Chem., v. 18, p. 355–372.
(6) HARRIS, J. E. 1917 Adsorption by soils. *In* Jour. Phys. Chem., v. 21, p. 454–473.
(7) HILGARD, E. W. 1906 Soils, p. 17–23. MacMillan, New York.
(8) LYON, T. L., AND BIZZEL, J. A. 1916 Calcium, magnesium, potassium, and sodium in the drainage water from limed and unlimed soil. *In* Jour. Amer. Soc. Agron., v. 8, no. 2, p. 81–87.
(9) LYON, T. L., AND BUCKMAN, H. O. The Nature and Properties of Soils, p. 345. MacMillan, New York.

(10) McINTIRE, W. H. 1921 The nature of soil acidity with regard to its quantitative determination. *In* Jour. Amer. Soc. Agron., v. 13, no. 4, p. 137–161.

(11) PARKER, E. G. 1913 Selective absorption by soils. *In* Jour. Agr. Res., v. 1, no. 3, p. 179–188.

(12) PLUMMER, J. K. 1918 Studies in soil reaction as indicated by the hydrogen electrode. *In* Jour. Agr. Res., v. 12, no. 1, p. 19–31.

(13) SHARP, L. T., AND HOAGLAND, D. R. 1916 Acidity and absorption in soils as measured by the hydrogen electrode. *In* Jour. Agr. Res., v. 7, no. 3, p. 123–145.

(14) SWANSON, C. O. 1914 Chemical analysis of some Kansas soils. Kans. Agr. Exp. Sta. Bul. 199, p. 633–715.

(15) SWANSON, C. O., LATSHAW, W. L., AND TAGUE, E. L. 1921 Relation of the calcium content of some Kansas soils to soil reaction as determined by the electrometric titration. *In* Jour. Agr. Res., v. 20, no. 11, p. 855–868.

(16) TRUOG, EMIL 1916 The cause and nature of soil acidity with special regard to colloids and absorption. *In* Jour. Phys. Chem., v. 20, p. 457–484.

(17) WAY, J. T. 1850–1852 On the power of soils to absorb manure. *In* Jour. Roy. Agr. Soc. Eng., v. 11, p. 313–379, and v. 13, p. 123–143.

"AUXIMONES" AND THE GROWTH OF THE GREEN PLANT[1]

NORMAN ASHWELL CLARK AND EMERY M. ROLLER

Iowa State College

Received for publication December 1, 1923

The possibility of the presence in the soil of growth-promoting accessory substances is still an open question. The nutrition of the green plant has generally been regarded as satisfied by a supply of inorganic food materials, consisting of mineral matter, carbon dioxide and water, from which organic material is produced and the complete plant structure built up. Recently, however, this conception has been questioned by Bottomley (1–6) and Mockeridge (15) who have stated that the addition of minimal quantities of certain organic substances to the inorganic nutrients is absolutely essential if the plants are to grow healthily and normally for any length of time.

To these organic substances Bottomley gave the name *auximones*, and it was suggested that they were similar in function to the growth-promoting accessory factors termed vitamines, necessary for the growth of animals. "It is now established that plants, in their turn, require growth-promoting substances, or auximones; which, in the case of the lower plants, are apparently manufactured by themselves, but which in the case of green plants, must be supplied from without. Since these necessary accessory substances are essentially organic in nature, their only possible source in the case of ordinary green plants is to be found in the organic matter of the soil in which they are growing."

Several patents were secured by Bottomley for the manufacture of these growth-promoting substances from bacteria-treated peats, and an effort was made to use the *auximones* on a commercial scale in both greenhouse and market garden practise. A popular account is given by G. D. Knox in *The Spirit of the Soil* and marked success is reported in many cases.

In order to avoid introducing the *auximone* in the seed, Bottomley worked in the laboratory principally with *Lemna minor* and *Lemna major* which reproduce by budding, using Detmer-Moor's and Knop's solutions (6). With these solutions he failed to get good growth and after a few weeks both the appearance and weight of the *Lemna* indicated that the plants were not receiving all that they required to maintain their normal health. Mockeridge (15) had the same experience with *Lemna major*. In both cases the addition of small quantities of organic matter, extracted from soil or from the specially treated peat, greatly increased the rate of reproduction and the health of the plants.

Mockeridge has quoted the work of Williams (20) who arrived at the conclusion that a substance identical with the water-soluble vitamine B was necessary for the growth of yeast. The experience of one of the writers with *Saccharomyces cerevisiae* (7) and recent work in these laboratories by Fulmer (9) and Nelson (16) as well as reports by McCollum and his co-workers (13) have shown that the accessory substance for yeast, the *Bios* of Wildiers (19), is of the nature of an accelerator rather than an essential for reproduction and cannot be compared with animal vitamines without which reproduction and growth cannot take place. Robertson

[1] Contribution from the Department of Chemistry, Iowa State College, Ames, Iowa.

(17) has suggested that this may be the same *substance X* which he finds accelerates the reproduction of infusoria.

It seemed possible therefore, that the function of organic matter in the nutrition of green plants might be to increase the speed of reproduction and growth, rather than serve as an essential constituent, and that the reason for poor growth in Knop's and Detmer's solutions might be the unsuitability of the media used. Bottomley (6) recognized this when using Detmer's solution alone: he therefore tested Knop's and found that it checked his results with Detmer's, but he does not seem to have tried others. Mendiola (14) in a genetic study of *Lemna minor*, reported successful growth and even increased size of plants with a modified Pfeffer's medium which contained no organic matter.

EXPERIMENTAL

After preliminary experiments *Lemna major* was chosen and the three salts, monocalcium phosphate, potassium nitrate and magnesium sulfate, were used as a basis of the medium. These salts were first tested by Livingston and Tottingham (12) for wheat. Iron was added to the solutions as ferric phosphate and was made up as described in the Plan for Coöperative Research of the National Research Council (11); approximately 0.38 mgm. of $FePO_4$ were added to 250 cc. of the solutions.

The calcium and magnesium salts were made up in 0.05 *M* solutions at 20°C. and the potassium nitrate 0.20 *M*. A modified Shive's apparatus (18) was used for filling and the plants were grown in Pyrex beakers which were wrapped to the level of the liquid with paper, black inside and white outside, and covered with a watch glass to prevent the entrance of dust. Each beaker contained 250 cc. of solution and this was changed twice a week as with Bottomley and Mockeridge: no trouble was caused by algae or mold under these conditions. The beakers were weighed and water lost was replaced each morning; specially redistilled conductivity water was used in all cases—the laboratory distilled water had a decidedly toxic effect on the plants. The stock cultures were grown in soil solutions, 25 gm. of a Carrington loam soil to 200 cc. water, and renewed weekly. All cultures received direct sunshine in the afternoon only.

One hundred and twenty-five solutions were made up, being all combinations of the three salts in the following proportions:

$Ca(H_2PO_4)_2$	KNO_3	$MgSO_4$
moles per liter	*moles per liter*	*moles per liter*
0.0004	0.0016	0.004
0.001	0.004	0.001
0.002	0.008	0.002
0.003	0.012	0.003
0.004	0.016	0.004

RESULTS

Within a week all plants in solutions containing 0.002 mole of monocalcium phosphate had turned brown and were dying or dead. This was not due to excess of calcium or phosphate for when the ions were rearranged, greater amounts were not harmful. On the other hand, 0.008 mole of KH_2PO_4 per liter proved toxic in several combinations. The effect of hydrogen ions is being further studied.

At the end of two weeks, twenty-two cultures which showed the best development with regard to size, color and number were selected for tests on their rate of reproduction. All were healthy and varied little in size from the controls in soil solution—a condition still shown after four months growth in the mineral solutions. The ratio of calcium to magnesium varied from 2.5 to 0.25.

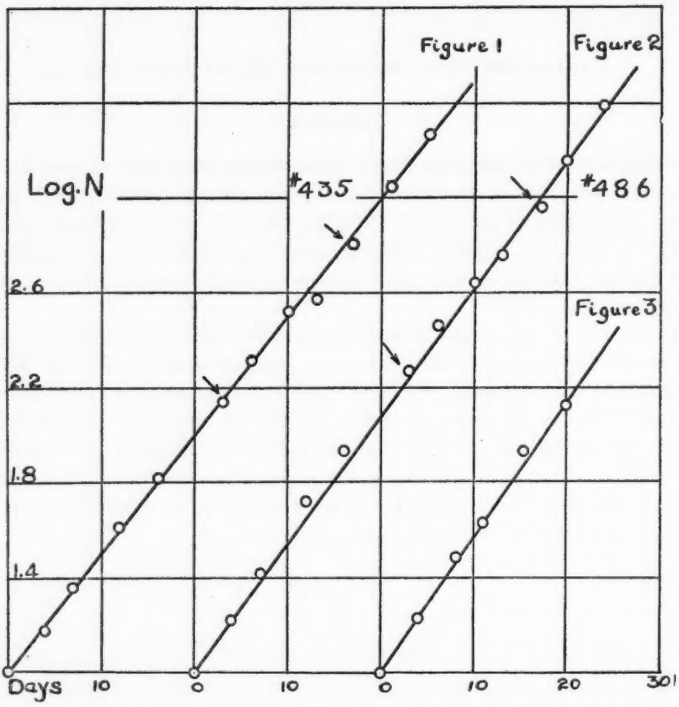
Given good conditions, the rate of increase at any time should be proportional to the number of plants present, whence

$$\log_{10} \frac{N}{N_o} = k\,(t - t_o)$$

If the logarithm of the number of plants is plotted on time, the result is a straight line with slope k. The variation in temperature and sunlight, and possibly the time of the growing season, would be expected to make the curve somewhat irregular, but remarkably uniform results were obtained. Two typical curves are shown in figures 1 and 2, solutions 435 and 486. At the points marked with the arrows the beakers became crowded and the number of plants was reduced to ten or twelve. As will be seen, this did not alter the slope of the curve. Figure 3 shows the soil control, which contained 25 gm. soil and 200 cc. water, changed twice a week as with the mineral solutions. The k for this is 0.058, indicating that a plant reproduced itself—the "generation time"—in 5 days, compared to $5\frac{1}{2}$ to $5\frac{3}{4}$ for the mineral solutions.

In figures 4 and 5 are plotted of Bottomley's curves for Detmer's solution alone and Detmer's plus peat extract (6). In both cases the plants started to reproduce during the first week at a rapid rate and a generation consisted of four to five days. This rate, however, was not kept up but fell to about twenty days for the mineral solution alone and to 11 days for the medium including the peat extract. Upon adding the extract the rate of reproduction was doubled but it did not approach that of the first seven days. Curves for Knop's solutions plotted from both Bottomley and Mockeridge show the same shape but the time is even longer.

No such drop is shown in figures 1 and 2, where the rate of growth continued at twice the speed shown after the first week in Bottomley's medium containing minerals and peat extract. The rate of reproduction shown in figure 1—after growing with sunshine during the afternoon only—was rather smaller than for the plants grown in Bottomley's greenhouse during the first

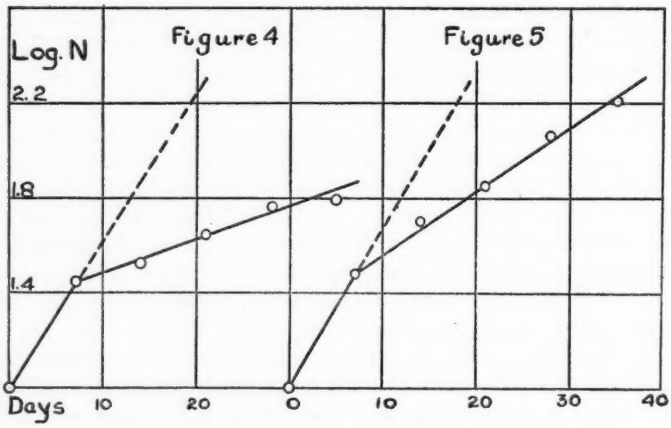


FIGS. 1–3. REPRODUCTION OF *Lemna* IN THREE SALT AND SOIL SOLUTIONS

FIG. 1. Solution no. 435. $Ca(H_2PO_4)_2$ = 0.0004 moles per liter; KNO_3 = 0.0004 moles per liter; $MgSO_4$ = 0.0004 moles per liter. k = 0.051. Generation time = 5.9 days.

FIG. 2. Solution no. 486. $Ca(H_2PO_4)_2$ = 0.001 moles per liter; KNO_3 = 0.004 moles per liter; $MgSO_4$ = 0.002 moles per liter. k = 0.053. Generation time = 5.6 days.

FIG. 3. Soil 25 gm.; water 200 cc. k = 0.057. Generation time = 5.2 days.



FIGS. 4–5. REPRODUCTION OF *Lemna* IN DETMER'S SOLUTION

FIG. 4. Detmer's solution plotted from Bottomley's tables. Generation time for first week = 4.7 days; after first week = 20 days.

FIG. 5. Detmer's solution plus peat extract, plotted from Bottomley's tables. Generation time for first week = 4.3 days; after first week = 11 days.

week in the peat solution, but this rate was almost maintained in the mineral solutions, whereas Bottomley's, even with organic matter present, dropped off rapidly.

It seems therefore, that better growth can be obtained by using a mineral solution suited to the plant than by adding organic matter to one in which the plant has difficulty in developing. For four months, representing over twenty generations, the *Lemna* without *auximones* reproduced at the same rate and the size and health of the plants showed no falling off. The suggestion that *auximones* act as essential constituents for growth of plants, in the same way as the vitamines for animals, must therefore be negatived. The question whether organic matter will function as an accelerator when the solution is adapted for the plant's needs is receiving further study in this laboratory.

SUMMARY

1. The growth of *Lemna major* in mineral solutions depends upon suitable concentrations of salts; organic matter is not necessary.

2. Reproduction, in varying concentrations of $Ca(H_2PO_4)_2$, KNO_3 and $MgSO_4$, with iron supplied as ferric phosphate, attained almost the speed for plants grown in solutions containing soil, and for four months the *Lemna* showed no signs of decrease in size.

3. The number of plants present follow closely the logarithmic equation $\log_{10} \frac{N}{N_o} = k(t - t_o)$. The time for one generation to produce another under the conditions given, for solutions containing soil was five days; for a number of different concentrations of the salts used a generation time of under six days was obtained.

4. *Auximones* are not essential for the growth and reproduction of green plants and cannot be classed with vitamines which are necessary for animal growth.

REFERENCES

(1) BOTTOMLEY, W. B. 1914 Some accessory factors in plant growth and nutrition. *In* Proc. Roy. Soc., Series B, v. 88, p. 237–247.

(2) BOTTOMLEY, W. B. 1914 The significance of certain food substances for plant growth. *In* Ann. Bot., v. 28, p. 531–540.

(3) BOTTOMLEY, W. B. 1917 Some effects of organic growth-producing substances (auximones) on the growth of *Lemna minor* in mineral culture solutions. *In* Proc. Roy Soc., series B, v. 89, p. 481–507.

(4) Bottomley, W. B. 1917 The isolation from peat of certain nucleic acid derivatives. *In* Proc. Roy. Soc., series B, v. 90, p. 39–44.

(5) BOTTOMLEY, W. B. 1919 The effect of nitrogen-fixing organisms and nucleic acid derivatives on plant growth. *In* Proc. Roy. Soc., series B, v. 91, p. 83–96.

(6) BOTTOMLEY, W. B. 1920 The growth of *Lemna* plants in mineral solutions and in their natural media. The effect of organic matter on the growth of various water plants in culture solutions. *In* Ann. Bot., v. 34, p. 345–365.

(7) CLARK, NORMAN A. 1922 The rate of formation and yield of yeast in wort. *In* Jour. Phys. Chem, v. 26, p. 42–60.

(8) FULMER, E. I., AND NELSON, V. E. 1922 Water-soluble B and "bios" in yeast growth. *In* Jour. Biol. Chem., v. 51, p. 77–81.

(9) FULMER, E. I., NELSON, V. E., AND SHERWOOD, F. F. 1921 The nutritional requirements of yeast. I. The rôle of vitamins in the growth of yeast. II. The effect of the composition of the medium on the growth of yeast. *In* Jour. Amer. Chem. Soc., v. 43, p. 186–199.

(10) FULMER, E. I., NELSON, V. E. AND WHITE, A. J. 1923. The growth of yeast on a medium of wholly synthetic origin. *In* Jour. Biol. Chem., v. 57, p. 397–399.

(11) LIVINGSTON, B. E. (ed.) 1919 Plan for coöperative research on salt requirements of representative agricultural plants. Johns Hopkins University, Baltimore.

(12) LIVINGSTON, B. E., AND TOTTINGHAM, W. E. 1918 A new three-salt nutrient solution for plant cultures. *In* Amer. Jour. Bot., v. 5, p. 337–346.

(13) MACDONALD, M. B., AND MCCOLLUM, E. V. 1921 The "bios" of Wildier's and the cultivation of yeast. *In* Jour. Biol. Chem. v. 46, p. 525–527.

(14) MENDIOLA, N. B. 1919 Variation and selection within clonal lines of *Lemna minor*. *In* Genetics, v. 4, p. 151–182.

(15) MOCKERIDGE, F. A. 1920 The occurrence and nature of the plant growth-producing substances in various organic manurial composts. *In* Biochem Jour., v. 14, p. 432–450.

(16) NELSON, V. E., FULMER, E. I., AND CESSNA, R. 1921 The nutritional requirements of yeast. III. The synthesis of water-soluble B by yeast. *In* Jour. Biol. Chem., v. 46, p. 77–81.

(17) ROBERTSON, T. B. 1921 (Article LXXIII.) Experimental studies on cellular multiplication. I. The multiplication of isolated infusoria. *In* Biochem. Jour., v. 15, p. 595–611.

(18) SHIVE, J. W. 1915 A study of physiological balance in nutrient media. *In* Physiol. Res., v. 1, p. 327–397.

(19) WILDIERS, E. 1901 Nouvelle substance indispensible au development de la levure. *In* La Cellule, v. 18, p. 313.

(20) WILLIAMS, R. J. 1919 The vitamine requirements of yeast. *In* Jour. Biol. Chem., v. 38, p. 465–486.

THE EFFECT OF DIFFERENT KINDS OF WOOD AND OF WOOD PULP CELLULOSE ON PLANT GROWTH[1]

J. A. VILJOEN AND E. B. FRED[2]

University of Wisconsin

Received for publication December 11, 1923

In Wisconsin there are large tracts of land which at one time were covered with forest but which are now cleared of timber. Much of the eight million acres of cut-over land in Wisconsin is suitable for tillage and at present attempts are being made to cultivate these soils. Colby silt loam, the prevailing soil type, is decidedly acid and requires three to four tons of limestone per acre to neutralize the soil acids. With the use of mammoth tractors and disc plows, it is possible to turn over the soils including all the brush and vegetable growth which has sprung up since the removal of the timber. The material turned under often includes young trees one to four inches in diameter and the usual forest débris of leaves, roots, and brush.

For the first year after cultivation, the crop yield has usually been unsatisfactory, due no doubt to several causes. In this paper are recorded some results obtained from a laboratory and greenhouse study of the effect of different kinds of wood on the growth of oats and clover on these cut-over soils.

It is evident that the bad physical condition of the soil, resulting from the presence of this organic matter, would in a certain measure be responsible for the crop depression. It was soon recognized that the elimination of this factor does not remedy the matter but that the wood still exerts a depressing effect. The other factors may be of a biological nature. It is possible that such wood constituents as essential oil, resins, and tannins, may exert a toxic action on the plants or that abnormal conditions may be set up by these wood constituents or their decomposition products. The latter would probably be tied up with the formation and accumulation of nitrates. Nitrification may be inhibited, the nitrates may be reduced, or the nitrates may be assimilated (1) by the organisms decomposing such wood constituents as tannins, resins, etc., (2) by the organisms decomposing the cellulose in the wood, and (3) by those destroying the decomposition products of the cellulose.

[1] Published with the approval of the Director of the Agricultural Experiment Station, Madison, Wisconsin.

[2] The authors are indebted to Mr. A. C. Fiedler for assistance in the carrying out of these experiments.

Only a few reports that deal directly with this subject have been found. Gibbs and and Werkman (4) investigated the effect of sawdust from various kinds of wood on ammonification and nitrification. They noted that the rate of nitrification of blood meal was slow and that there was an accumulation of ammonia. The nitrification of ammonium sulfate was depressed to a large degree. These investigators believed the depression is not due to a reduction of the nitrate but to an inhibition of the nitrate-forming organisms. Koch (6) found an entire absence of nitrate in soil containing 0.33 per cent cellulose as filter paper. In this soil he grew plants which attained the following dry weights:

	without paper	*with paper*
Buckwheat	22.0 gm.	3.0 gm.
Mangels	17.7 gm.	1.1 gm.

Eighteen months after treatment all the paper had disappeared and the soil began to show nitrate formation. He was able to demonstrate a considerable gain in total nitrogen in soil containing 3.0 per cent cellulose, some glucose, and which had been inoculated with azotobacter. In the first experiment, he did not estimate the total nitrogen and in the second he failed to measure the nitrates. In another paper, Koch (7) found that turpentine, resins, and tannins were toxic to plant growth and prevented nitrate accumulation. He suggests that these substances may be sources of energy for the denitrifying bacteria. In a later report (8) he found the same results but thought that the tannins might have had a toxic effect on the nitrate organisms.

Various other workers have reported on the nitrate content of forest soils: Baumann (1), and Henry (5) found that such soils are low in nitrate and that their power to form nitrates is low. Henry (5) also found that some forest soils gained in total nitrogen. Moriya (9) found that forest soils were high in nitrogen. Falckenstein (3) found that forest soils not lacking in lime could gain in nitrate.

EXPERIMENTAL WORK

In these experiments a virgin Colby silt loam, obtained from the timber area, was used. The dry soil contained the following percentages of nitrogen, phosphorus and potassium:

Nitrogen	0.088
Phosphorus	0.030
Phosphorus (available)	trace
Potassium	1.800

In order to make the tests somewhat similar to field conditions, the young trees or brush from the plot where the soil was taken were also saved and used in the experiments. It was found that the average weight of the green brush from an area of 10 square feet was 75 lbs. This consists of birch, willow, poplar and alder.

After a thorough mixing, the soil was filled into 4-gallon jars and the various woods added. The amount of wood to use was estimated from the weight of the brush on a known area. The first treatment, 1.5 per cent green weight, is approximately the same amount as turned under in the field; the second, 3.0 per cent green weight is more than is commonly applied. Aside from a comparison of the effect of the different woods, it was planned to try out the influence of size of wood particles and also the effect of ash from the various woods.

Two crops were sown, oats and red clover; the latter being subdivided into two sections, inoculated and uninoculated.

After the different applications of wood had been made, the soil moisture was brought up to 20 per cent. The soil was kept in this condition for sixty days and then planted. One-half of the jars, in duplicate, were planted to Swedish Select oats and the other half to red clover. For the plan and general treatment see the figures of tables 1 and 2.

TABLE 1

The effect of different kinds of wood on the growth of oats

NUMBER	TREATMENT	WEIGHT OF DRIED OAT PLANTS			
		Birch	Willow	Alder	Poplar
		gm.	gm.	gm.	gm.
1	None, control	26.6	26.6	26.6	26.6
2	1.5 per cent wood coarse*	19	19	17	18
3	3.0 per cent wood coarse*	15	15	15	14
4	3.0 per cent wood fine*	28	24	15	17
5	3.0 per cent wood burned and ash used	26	29	29	26

* Green.

TABLE 2

The effect of different kinds of wood on the growth of red clover

NUMBER	TREATMENT	WEIGHT OF GREEN CLOVER PLANTS							
		Birch		Willow		Alder		Poplar	
		Not inoculated	Inoculated	Not inoculated	Inoculated	Not inoculated	Inoculated	Not inoculated	Inoculated
		gm.	gm.	gm.	gm.	gm.	gm.	gm.	gm.
1	None, control	27.5	44	27.5	44	27.5	44	27.5	44
2	1.5 per cent wood coarse*	21	23	34	43	24	43	27	40
3	3.0 per cent wood coarse*	22	38	30	45	17	50	17	39
4	3.0 per cent wood fine*	21	33	30	33	14	44	33	56
5	3.0 per cent wood burned and ash used	54	54	67	60	56	58	63	52

* Green.

Almost without exception, the turning under of wood proved harmful to the growth of oats and in some cases to a very marked degree. This injury is far more noticeable in the case of alder and poplar than with birch and willow. Apparently the readily available part of the birch and of the willow was decomposed before the oats were planted. As might be expected, the decreased yield is greatest with the large application of wood. On the other hand the ash from the various woods failed to show any injury and frequently brought about a gain in growth of the oats and a very noticeable gain in the growth of the clover.

Plates 1, 2, and 3 show very clearly the effect of the different woods on the growth of oats. Without exception the plants in the jars containing the wood were a yellowish green color instead of the dark green noted in the control. From general appearances, these plants in the jars treated with wood suffered from lack of available nitrogen. Additional support for this statement is found in the results of the nitrate analysis. No nitrate nitrogen was found in the soil of the jars treated with wood while the controls showed small amounts.

The effect of the different woods on red clover is shown in table 2. In the main these results agree with those obtained from the oat experiment.

One point of special interest in the table is the decided improvement in growth of the inoculated red clover as compared with the uninoculated.

Where ashes are applied, this sharply defined influence of inoculation is not noted. To see if this good growth of the clover in the ash-treated soil is a result of plant food or of natural inoculation rendered effective by the food constituents of the ash, the roots of the inoculated and uninoculated plants in the ash-treated group were carefully examined for nodules. All of the inoculated plants showed nodules while all of the uninoculated plants were free of nodules. The evidence seems conclusive—nodule bacteria of red clover are not present in this soil, or if present, only in small numbers.

NATURE OF THE INJURIOUS FACTOR

In order to gain some idea of the nature of this injurious factor, a series of tests were carried out. In these experiments only dried white birch wood was used. The wood was chopped to coarse chips and these were then ground in a mill to a coarse sawdust that would pass a ten-mesh sieve. In the tumbler experiments, 80-mesh sawdust, obtained by rasping the wood with a fine rasp, was used. In the greenhouse experiments, 2-gallon jars with side bottom drainage were used. All experiments were conducted at 25 per cent moisture content which was kept constant by weighing at regular intervals and adding the necessary amount of distilled water. The lime used was a natural limestone of about 106 per cent calcium carbonate equivalent and passed an 80-mesh sieve. The manure was well-rotted horse manure and had passed a $\frac{1}{4}$-inch screen. It contained very little straw.

The effect of sawdust on the growth of oats

In this series, lime, manure, and lime with manure were added to the soil with the sawdust, and a study made of the effect on the growth of the oats and the nitrate content of the soil. After the oats were planted, the jars were made up to the required moisture content. When the seedlings were about three inches high, they were thinned so that each jar had fifteen plants.

During the first two weeks no differences could be noticed between the plants where sawdust was present and those where none was present. At

the end of this time, however, the plants in the jars treated with sawdust began to develop a yellow color, the stems and leaves were thin and rigid and towards the end of the experiment they became badly infected with rust. The plants in the untreated jars were healthy, succulent and of a good color. In the soil containing sawdust, very little response to the addition of lime, manure, or lime with manure was obtained; while in the untreated soil very good responses were obtained especially with both lime and manure. The plants were cut after nine weeks and soil samples taken the same day and analyzed for nitrate. The results are shown in table 3.

At the end of the experiment no nitrates were present in the soil which had received wood. The dry weights of the plants grown in the presence of wood were less than those of the plants grown in the absence of wood.

From these results it appears that the depression in the growth of the oats was due to a lack of nitrate nitrogen rather than to any toxic constituents in the wood.

TABLE 3

The effect of sawdust on the growth of oats and the nitrate content of the soil

NUMBER	TREATMENT*	NITROGEN AS NITRATE IN 100 GM. DRY SOIL	DRY WEIGHT OF PLANTS
		mgm.	*gm.*
1	Untreated, control	2.13	5.2
2	80 gm. wood	0.00	3.2
3	16 gm. lime	5.65	8.0
4	16 gm. lime, 80 gm. wood	0.00	3.6
5	80 gm. manure	2.73	8.5
6	80 gm. manure, 80 gm. wood	0.00	4.2
7	16 gm. lime, 80 gm. manure	8.62	10.5
8	16 gm. lime, 80 gm. manure and 80 gm. wood	0.00	4.8

* 8 kilograms of soil in each jar.

The effect of wood pulp cellulose on the growth of oats and the nitrate content of the jars

This experiment was the same as the preceding in all respects, except that Carrington silt loam was used instead of Colby silt loam. The wood was replaced by wood pulp cellulose obtained from spruce by the Burgess process. The pulp was extracted with warm 5 per cent hydrochloric acid before it was incorporated into the soil, and then washed with several changes of boiling water. In this way it was hoped that the possibility of toxic wood constituents would be removed, and any depression in the growth would be due to the lack of nitrate or to the toxic action of cellulose decomposition products rather than toxic bodies of the wood.

Very early in the experiment there was a marked depression on the plants growing in the soil which had received the cellulose. Here the plants showed the same peculiarities as with the wood, but to a much more marked degree.

There was very little response to lime, manure, or lime with manure, while on the untreated soil these substances proved most beneficial. When the plants on the treated soil had reached a height of about six inches they became so infected with rust that the experiment had to be discontinued. The stems and leaves were thin and rigid and had a yellow color typical of nitrate starvation. The dry weights of the plants and the nitrate content of the soil are given in table 4. Here again it is noticed that the soil which had been treated with cellulose contained no nitrate. The phenoldisulfonic reagent did not give the slightest color. These results agree with those of Koch who found that soil which contained 0.33 per cent of filter paper contained no nitrate nitrogen. The soil had recuperated after eighteen months and he could find nitrate again. This experiment leaves no doubt about the fact that the lack of nitrate is due to the cellulose decomposition. That this lack is actually due to a reduction is shown by the following experiment.

TABLE 4

The effect of woodpulp cellulose on the growth of oats and the nitrate content of the soil

NUMBER	TREATMENT*	NITROGEN AS NITRATE IN 100 GM. DRY SOIL	DRY WEIGHT OF PLANTS
		mgm.	*gm.*
1	Untreated, control	3.24	9.7
2	100 gm. cellulose	0.00	2.4
3	16 gm. lime	4.83	10.0
4	16 gm. lime, 100 gm. cellulose	0.00	2.3
5	80 gm. manure	3.78	12.1
6	80 gm. manure, 100 gm. cellulose	0.00	2.6
7	16 gm. lime, 80 gm. manure	8.94	18.2
8	16 gm. lime, 80 gm. manure, 100 gm. cellulose	0.00	2.7

* 8 kilograms of soil per jar.

The reduction of nitrate in the soil by cellulose and sawdust

To show on a definitely quantitative basis that wood and cellulose can reduce nitrate in the soil, an experiment was carried out in tumblers of soil in the laboratory. A garden soil containing 50–60 parts per million of nitrate nitrogen was used. The exact nitrate content of the soil was measured and the wood and cellulose added in varying amounts. The wood was added as 80-mesh sawdust and the cellulose as absorbent cotton which had been cut to a fine state with a pair of scissors. The tumblers were kept at 25 per cent moisture content, room temperature, and covered with petri dishes.

At the beginning of the experiment the soil contained 5.31 mgm. nitrate nitrogen per 100 gm. dry soil. The results after four weeks are given in table 5. The control gained very little during the four weeks and 0.25 per cent cellulose was enough to reduce all the nitrate during that time. In the case of the wood 0.25 per cent reduced the nitrate about 50 per cent, while 0.5 per cent was enough to completely destroy it.

The effect of sawdust on the nitrification of bloodmeal

A study was made of the effect of wood on the nitrification of an easily nitrifiable substance such as blood meal. The amounts added are much larger than what would be added under field conditions. The experiment was carried out under the same conditions as former tests. An untreated soil blank was run as a control, one contained no wood, and the soil in the other tumblers contained 0.5 gm. bloodmeal together with varying amounts of wood as 80-mesh sawdust. After four weeks the tumblers were all analyzed for nitrate.

TABLE 5

The reduction of nitrate by cellulose and sawdust

NUMBER	TREATMENT	NITRATE NITROGEN PER 100 GM. DRY SOIL
		mgm.
1	Untreated, control	5.31
2	0.25 per cent cellulose	0.00
3	0.5 per cent cellulose	0.00
4	0.25 per cent sawdust	2.53
5	0.5 per cent sawdust	0.00
6	1.0 per cent sawdust	0.00

TABLE 6

The effect of sawdust on the nitrification of bloodmeal

TUMBLER NUMBER	TREATMENT OF 100 GM. SOIL	N AS NO_3 IN 100 GM. DRY SOIL	AMOUNT OF BLOODMEAL NITRIFIED
		mgm.	*per cent*
1	Untreated, control	6.60	
2	0.5 gm. blood meal	51.36	59.7
3	0.5 gm. blood meal, 0.25 gm. sawdust	42.92	47.9
4	0.5 gm. blood meal, 0.5 gm. sawdust	33.40	35.3
5	0.5 gm. blood meal, 1.0 gm. sawdust	30.00	30.8
6	0.5 gm. blood meal, 2.0 gm. sawdust	23.10	21.8

From the results in table 6 it is seen that the wood depresses nitrate accumulation to a very marked degree. The control containing neither wood nor bloodmeal gained very little in nitrate, while the blank containing only bloodmeal made a considerable gain. The soil at the beginning of the experiment contained 6.37 mgm. nitrate nitrogen per 100 gm. dry soil.

The effect on sawdust on the growth of inoculated peas

Since the depression caused by the presence of sawdust was, as far as could be seen, due to the lack of nitrate, it should be possible to grow peas in the presence of sawdust, without their suffering any ill effects, provided they could be inoculated and a liberal supply of lime were present.

To test this out, the peas were grown in half-gallon jars containing 3 kgm. white quartz sand. A Hopkins and Pettit solution with nitrogen omitted was added as a source of nutrient salts. At the beginning of the experiment each jar received 500 cc. of the solution and three weeks later an additional 500 cc. Jars 1 and 2 received 30 gm. of lime; jars 3 and 4 received the same amount of lime plus 30 gm. of sawdust. The seeds were germinated in moist sand and seedlings of the same size and strength transplanted into the jars and inoculated at once. Each jar contained four plants.

During the entire time of the experiment no differences between the two sets of plants could be noticed. They were of the same size and color.

This experiment and also the results of table 2 indicate that there is no appreciable toxic effect due to the wood constituents. Both sets showed good inoculation and since they could provide for their own nitrogen they did not suffer from the lack of nitrate.

TABLE 7

The effect of sawdust on the nitrate accumulation in soil treated with bloodmeal and lime

AGE OF CULTURE	NITRATE NITROGEN PER 100 GM. DRY SOIL	
	With wood	Without wood
days	*mgm.*	*mgm.*
0	2.08	2.08
2	1.44	2.08
4	1.69	2.08
7	1.69	2.08
14	5.55	8.67
21	12.7	31.20
28	19.68	39.00
35	24.96	40.04
42	26.69	
49	31.55	47.14
56	40.21	57.20
128	44.7	58.48

The effect of sawdust on the accumulation of nitrate in the soil from the nitrification of bloodmeal

In this experiment the accumulation of nitrate from an easily nitrifiable substance in the form of bloodmeal was studied for a considerable length of time in soil treated with lime and wood. A large number of flasks containing 200 gms. of a cropped Colby silt loam, 1 gm. of bloodmeal, 2 gms. of lime, and 2 gms. of sawdust, were set up together with a number of blanks without sawdust. These were kept at 25 per cent moisture content and at room temperature. To insure optimum aeration the contents of each flask were stirred after one week. Nitrates were determined after 2, 4, and 7 days and after that time at the end of every week. Duplicate flasks were analyzed and good checks were obtained.

The results are seen in table 7. During the entire duration of the experiment the nitrate in the flasks with the wood was considerably lower than in the blanks. Towards the end there seemed to be some recovery. Koch (6) also found a recoverv in jars treated with filter paper. After eight months he found no nitrate in soil which at the beginning contained nitrate; after eighteen months he again found up to 20 parts per million of nitrate nitrogen. This recovery is undoubtedly due to a diminution in the amount of cellulose present. Charpentier (2) found that in cylinders where he had added 1 per cent of cellulose to the soil, 70 per cent of the added cellulose had disappeared after twenty-eight weeks. In the case of the sawdust the recovery would be much more rapid, because the cellulose material is comparatively inaccessable and the large amounts of organic nitrogen in the form of bloodmeal would hasten the decomposition, as was found by Charpentier (2).

With such high amounts of nitrifiable organic matter present as in this experiment, the rate of nitrification was undoubtedly much greater than the rate of reduction, and since the reduction decreased with the cellulose available, towards the end it was very small and a much larger accumulation of nitrates resulted.

SUMMARY

The foregoing experiments show that the unfavorable action of wood on plant growth is due to a lack of nitrate in the soil. This loss of nitrate nitrogen is no doubt due to the great increase in the assimilation of nitrates by microörganisms. Since the same results can be obtained with wood-pulp cellulose as with wood, it does not seem likely that there is any toxic action on the plant due to such wood constituents as essential oils, resins, and tannins. When added in large amounts, Koch (7) showed that these substances are toxic to plants, however, the white birch used in this investigation only contained about 2.5 per cent tannin and the other constituents in even lesser amounts. The very small amounts of these substances derived from the added wood (1 per cent) could hardly have any appreciable effect on the growth of plants.

Certain kinds of wood, for example, alder or poplar, are more injurious than birch or willow. This difference is due perhaps to the variation in rate of decomposition. The alder and poplar are decomposed more slowly than the other woods, and hence their injurious effect is noted for a longer time.

Since inoculated peas can be grown in the presence of sawdust without showing any ill effects, it seems that the injury from wood cannot be due to the presence of a poisonous substance.

The experiments also show that the lack of nitrate is due to a reduction rather than to an inhibition of nitrification, and that this reduction is caused by a group of organisms which make use of cellulose. No evidence has been obtained as to which group is responsible for this reduction. It may be due

to the organisms which decompose cellulose directly, or to those groups which live on its fermentation products.

That nitrification takes place is shown by the fact that with large amounts of bloodmeal in the soil the rate of nitrification can be so increased that it exceeds the rate of reduction and an accumulation of nitrate takes place.

The results of these tests taken as a whole indicate that the reduced growth of plants following the application of young wood is closely connected with a loss of nitrates. This injury soon passes off and the following season is almost without effect.

REFERENCES

(1) BAUMANN A. 1887 Über die Bestimmung des im Boden enhaltenen Ammoniakstickstoffes and über die Menge des Assimilierbaren Stickstoffes im unbearbeiteten Boden. *In* Landw. Vers. Stat., v. 33, p. 247–303.

(2) CHARPENTIER, C. A. G. 1921 Einfluss des Mistes auf die Zellulose Zersetzung in der Ackererde. Travastehus, Doct. Thesis, Univ. of Helsingsfors.

(3) FALCKENSTEIN, K. VOGEL VON, 1913 Nitrate formation in forest soils. *In* Intern. Mitt. Bodenk., v. 3, no. 6, p. 494.

(4) GIBBS, W., AND WERKMAN, C. H. 1922 Effects of tree products on the bacterial activities of the soil. *In* Soil Sci., v. 13, no. 4, p. 303.

(5) HENRY, E. 1897 L'azote et la Vegetation Forestiere. *In* Ann. de la Sc Agron., 2nd series, v. 2, p. 359.

(6) KOCH, A. 1910 Über Luftstickstoffbindung im Boden mit Hilfe von Zellulose als Energiematerial. *In* Centbl. Bakt., Abt. 2, v. 27, p. 1–7.

(7) KOCH, A. 1914 Über die Einwirkung des Laub- und Nadelwaldes auf den Boden und die ihn bewohnenden Pflanzen. *In* Centbl. Bakt., Abt. 2, v. 41, p. 545–572.

(8) KOCH, A., AND OELSNER, ALICE 1916 Einfluss von Fichtenharz und Tannin auf den Stickstoffhaushalt des Bodens und seine Physikalische Eigenschaften. *In* Centbl. Bakt., Abt. 2, v. 45, p. 107–118.

(9) MORIYA, S. 1915 Composition of fallen leaves of forest trees, and their quantities. *Abs. in* Chem. Abs., v. 11, p. 1513.

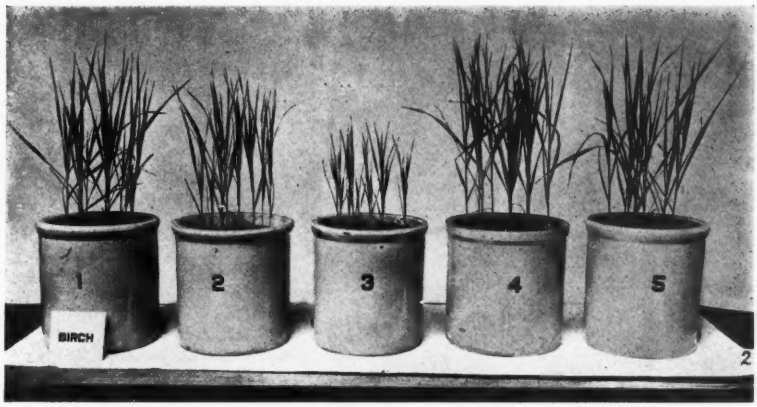


FIG. 1. THE EFFECT OF BIRCH ON OATS

Jar 1. Control, no birch
Jar 2. 225 gm. coarse birch
Jar 3. 450 gm. coarse birch
Jar 4. 450 gm. fine birch
Jar 5. Ashes from 450 gm. birch

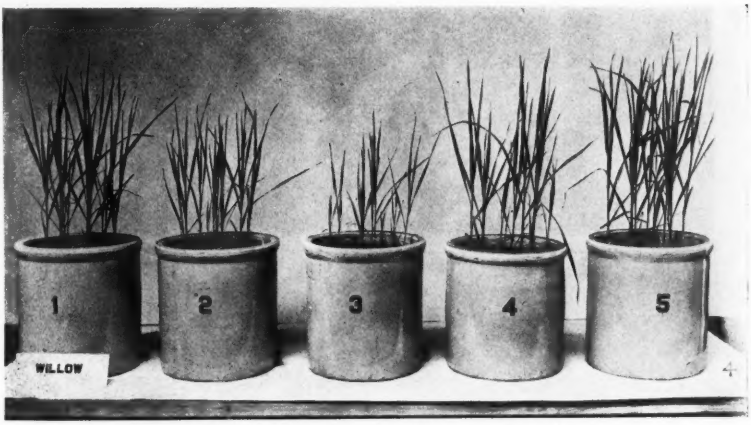


FIG. 2 THE EFFECT OF WILLOW ON OATS

Jar. 1 Control, no willow
Jar 2. 225 gm. coarse willow
Jar 3. 450 gm. coarse willow
Jar 4. 450 gm. fine willow
Jar 5. Ashes from 450 gm. willow

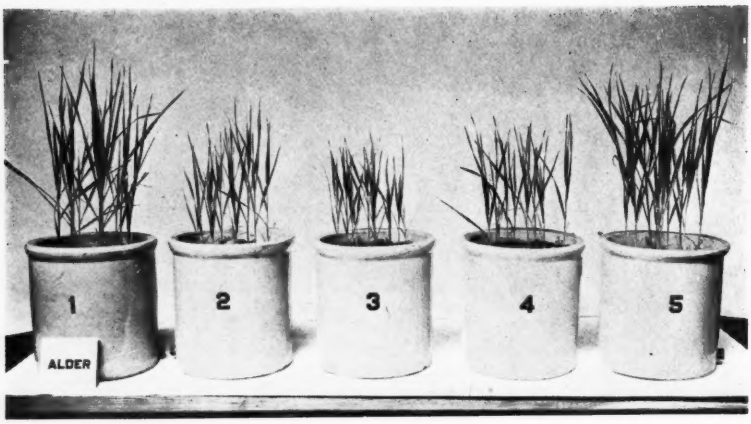


FIG. 1. THE EFFECT OF ALDER ON OATS

Jar 1. Control, no alder
Jar 2. 225 gm. coarse alder
Jar 3. 450 gm. coarse alder
Jar 4. 450 gm. fine alder
Jar 5. Ashes from 450 gm. alder

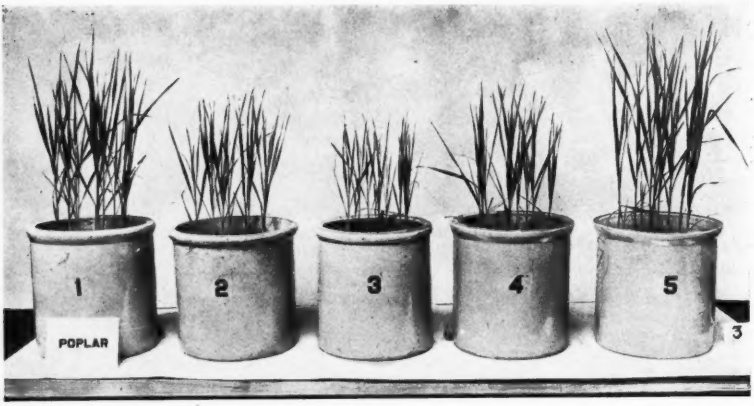
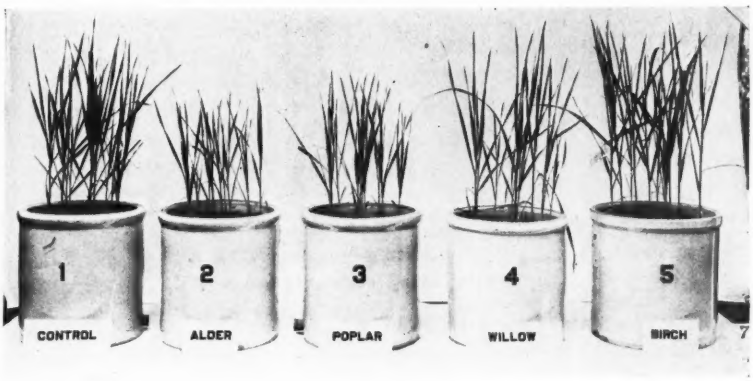


FIG. 2. THE EFFECT OF POPLAR ON OATS

Jar 1. Control, no poplar
Jar 2. 225 gm. coarse poplar
Jar 3. 450 gm. coarse poplar
Jar 4. 450 gm. fine poplar
Jar 5. Ashes from 450 gm. poplar



THE EFFECT OF VARIOUS KINDS OF WOOD ON THE GROWTH OF OATS

EASILY SOLUBLE CALCIUM OF THE SOIL IN RELATION TO ACIDITY AND RETURNS FROM LIMING[1]

F. L. DULEY[2]

University of Wisconsin

Received for publication December 17, 1923

The work reported in this paper was carried out for the purpose of studying the relation between the easily soluble calcium in the soil and the returns obtained from the use of lime in the field. It was hoped that some information might be gained which would help to explain further why certain strongly acid soils are able to produce good yields of all the common farm crops including red clover and alfalfa, while on the other hand some slightly acid soils may require liming before satisfactory crops can be grown. It is a vital question whether there are not other factors that may in many cases assume an importance quite as great as the acidity itself in determining the need of a soil for lime.

Conner (5) and others have called attention to the effect of soluble aluminum in certain soils. Truog (26) points out that it may be largely a matter of the ability of the plant to get the calcium necessary for its own development. He has called attention to the difference in the feeding power of different crops for calcium. It would seem from this that the amount of soluble calcium in some form in the soil or soil solution may be of great significance in furnishing to a particular crop the amount of this element which it needs. This more or less readily soluble calcium may be of importance in making other necessary elements "physiologically available" as has been shown by True (23 and 24). Hoagland (9) has also pointed out that substances may be absorbed at different rates under varying hydrogen-ion concentrations, even with equal total salt concentrations. Bryan (4) found greater amounts of calcium in alfalfa and clover plants grown in nutrient solutions with low hydrogen-ion concentrations. McCall (13) concludes after reviewing some of the more recent work on soil acidity, that the common opinion that the application of lime must be carried to the point of neutralization, must be revised and modified, in view of the fact that many crops make satisfactory growth on soils which are regarded as acid.

Wolff (29) showed as early as 1871 that the amount of calcium found in plants of different species varied between wide limits and the range was quite marked even in the same species, when grown under different conditions. White (28) found that red clover and sorrel increased

---

[1] Part of a thesis submitted to the Faculty of the Graduate School of the University of Wisconsin in partial fulfillment of the requirements for the degree of Doctor of Philosophy, June 1923.

Published with the permission of the Director of the Wisconsin Agricultural Experiment Station.

The writer wishes to express his appreciation of the valuable help and suggestions given by Professor A. R. Whitson under whose direction this work has been done.

[2] Associate Professor of Soils at the University of Missouri.

in content of calcium when limestone was added to soil from the Pennsylvania plots, having an indicated lime requirement of 5200 pounds an acre.

Petrographic examinations of soils by Plummer (19) demonstrated the existence of calcium in soils in a number of different minerals, particularly the silicates. This work was substantiated by Shorey, Fry, and Hazen (21) and they further demonstrated that some of the calcium silicates are easily soluble in a weak acid, while others resist the action of stronger acids. Their data show that in many cases soils with approximately the same total calcium content may vary widely in the amount of calcium existing as easily soluble silicates. Ames and Gaither (2) found that the percentage of calcium soluble in 0.2 *N* HNO_3 varied from 1.1 per cent to 88.7 per cent of the total calcium found in two different sandy loams.

Ames (1) showed that when dried blood was nitrified in an acid silt loam soil the amount of water soluble calcium was greatly increased.

MacIntire and Willis (11), Conner (5), Hartwell and Pember (7) and Mieth (15) showed that plants may very readily and efficiently obtain their calcium from silicates.

Holleman (10), Mitscherlich (16), Engels (6), Maschhaupt (12) and Shedd (20), studied the effect of carbonated water upon the solubility of the calcium of the soil.

Ames and Schollenberger (3) state that in some soils there was a fairly good relation between the calcium and magnesium soluble in 0.2 *N* HNO_3 and the Truog acidity test.

PLAN OF INVESTIGATION

Since a large part of the work on the subject of soil acidity has been done in the laboratory and since, on the other hand, the actual need of a particular soil for lime has usually been determined by field tests, it seemed desirable to correlate in a more definite way some of the results of these two methods of experimentation. It was planned to work, for the most part, with soils in which the need for lime treatment in the field had been more or less definitely determined by experiment, since the final test of a soil's need for lime must be made in the field. Samples from the untreated and limed portions of these experimental fields were collected and brought to the laboratory for analysis. Determinations were made of various factors which might have a bearing upon, or help to explain, the results obtained from the use of lime in the field. For most of the soils these determinations consisted of the following:

Total calcium, Total magnesium, Calcium content of the soil solution, Calcium soluble in 0.04 *N* carbonated water, Soil acidity by the Truog test, Total nitrogen and total phosphorus; the H-ion concentration of the displaced soil solution, (on the greenhouse soils), Calcium soluble in 0.20 *N* HNO_3.

A few soils for this work were collected in the autumn of 1921 for pot tests and for use in perfecting the methods to be used in the latter part of this study. The soils collected at this time consisted of Carrington silt loam and virgin and cropped Miami silt loam from the Keyser Farm near Madison, Wisconsin. The others were Plainfield sand and Colby silt loam from the Hancock and Marshfield substations in central Wisconsin.

In May, 1922, samples of soil were collected from fields in Wisconsin where the results of liming had been demonstrated. These samples were taken to a depth of seven inches and were collected in paraffined paper bags. A part

of each sample was used for displacement of the soil solution, and the remainder dried in the greenhouse for a determination of the calcium soluble in 0.04 *N* carbonated water. In addition to the soil samples from Wisconsin, other samples were collected from several of the soils experiment fields in Missouri.

EXPERIMENTAL WORK

In the first part of this paper will be reported the determinations made upon the soil solution. The method used in obtaining this soil solution was practically the same as that described by Parker (18). The calcium determinations were made on a 50-cc. sample of the displaced soil solution.

TABLE 1

Effect of liming upon the calcium content of the soil solution—samples taken in the spring of 1922

LAB. NO.	LOCATION	SOIL TYPE	Ca PER ACRE IN SOIL SOLUTION*		INCREASE DUE TO LIME
			Not limed	Limed	
			lbs.	*lbs.*	*lbs.*
	Missouri				
207, 208	Windsor	Oswego silt loam	15.2	19.5	4.3
	Wisconsin				
236, 237	Shawano County	Not determined	40.3	42.4	2.1
238, 239	Shawano County	Not determined	36.6	42.4	5.8
241, 242	Janesville	Waukesha silt loam	26.5	40.0	13.5
250, 251	Stockton	Sand knoll	6.1	8.2	2.1
252, 253	Stockton	Plainfield sandy loam	11.3	6.1	−5.2
274, 275	Plover	Waukesha sand (1)	11.3	7.6	−3.7
274, 276	Plover	Waukesha sand (2)	11.3	11.0	−0.3
278, 283	Hancock	Plainfield sand	6.3	9.5	3.2
279, 281	Hancock	Plainfield sand	7.1	8.7	1.6
286, 287	Neilsville	Colby silt loam (rolling phase)	18.6	39.0	20.4
289, 290	Almond	Plainfield sandy loam	15.6	28.1	12.5
291, 292	Neilsville	Vesper fine sandy loam	18.8	44.4	25.6
Average			17.3	23.6	6.3

* All calculations are made on basis of 2,000,000 pounds of dry soil per acre.

EFFECT OF LIMING

Liming slightly increased the calcium content of the soil solution as shown by table 1. On only two of the twelve soils shown in this table is the reverse true. It is difficult to explain these two exceptions to the general rule. It seems probable, however, that since the calcium content of these sandy soils was low and the clover or alfalfa crop fairly heavy, the apparent decrease from lime had really been absorbed by the crop. This assumption is supported by the results shown in table 3, where the calcium absorbed by the clover is greater than the decrease found in the soils shown in table 1. In

table 2 the effect of lime in conjunction with fertilizers is shown. It may be seen from this table that there are three cases out of nine where the limed land had less calcium in solution than did the unlimed. This again is probably due to a greater absorption by the crop on these plots.

The calcium in the soil solution varies widely under different conditions in the same soil. The results shown in tables 1, 2 and 3 are from samples taken during the spring of 1922. If the amount 37.6 pounds of calcium per acre in solution shown in table 3 for untreated Colby silt loam is compared with the soluble calcium in the same soil kept in the greenhouse for six months (table 4), it will be seen that there is a difference of 279.2 pounds. This is

TABLE 2

Effect of lime in conjunction with manure or fertilizer upon the calcium content of the soil solution

LAB. NO.	LOCATION	SOIL TYPE	MANURED OR FERTILIZED LAND. Ca PER ACRE IN SOIL SOLUTION		INCREASE DUE TO LIME
			No lime	Limed	
			lbs.	*lbs.*	*lbs.*
	Missouri				
229, 219	Strafford	Lebanon silt loam	29.4	33.6	4.2
224, 223	Willow Springs	Clarksville silt loam	22.8	27.8	5.0
225, 223	Willow Springs	Clarksville silt loam	29.9	27.8	−2.1
234, 233	Cuba	Lebanon silt loam	14.7	21.1	6.4
150, 151	Maryville	Marshall silt loam	36.0	58.6	22.6
	Wisconsin				
245, 246	Janesville	Waukesha silt loam	32.8	27.7	−5.1
265, 262	Marshfield	Colby silt loam	32.4	42.6	10.2
272, 273	Coddington	Peat	57.9	51.4	−6.5
281, 282	Hancock	Plainfield sand	5.5	9.1	3.6
Average			29.0	33.3	4.2

* Samples taken in spring 1922.

due to the fact that the latter sample was collected in the fall of 1921 and kept in the greenhouse until March 3, 1922. The other sample which had only 37.6 pounds calcium in the soil solution was collected May 20, 1922, after it had received numerous spring rains and was supporting a good growth of clover. According to the results of McCool and Millar (14) it would seem that the percolation of rain water has carried the calcium salts downward into the subsoil below the top 7-inch layer and probably has leached much of it entirely from the soil. The calcium in solution in the greenhouse soils may also have been increased by the drying of these soils, before the crop was started.

EFFECT OF THE CROP UPON THE CALCIUM CONTENT OF THE SOIL SOLUTION

Hoagland (8) has shown by measuring the depression of the freezing point that a crop materially reduces the total amount of salts in the soil solution.

That the crop absorbs calcium from the soil solution to an extent that can be measured in the displaced soil solution may be seen from table 3, where land having a rank growth of clover is compared with similar land having no crop, or which had just recently been planted to a spring crop. Sample 259 was taken from near the centre of the bare spots where the clover had been killed the previous year by the grain shocks. Sample 258 was taken from the clover land only a few feet away from sample 259. There was approximately two tons of clover hay per acre on the land at this time, May 20, 1922. When the crop was harvested about the middle of June the yield was three

TABLE 3

Effect of clover growth upon the calcium content of the soil solution

LAB. NO.	SOIL TREATMENT*	Ca PER ACRE IN THE SOIL SOLUTION		Ca TAKEN FROM SOIL SOLUTION BY CROP
		Clover land	Uncropped land	
		lbs.	*lbs.*	*lbs.*
258	Clover field, new farm. Good clover	44.4		
259	Same field. Bare spots under shocks		57.3	12.9
256	Agronomy plot. Corn just planted		72.7	28.3
257	Series 800. Land plowed		67.6	23.2
260	Plot 102A. Good clover (check)	37.6		
266	Plot 202A. Barley just coming up		82.6	45.0
265	Plot 108A. Clover (manure Rock Phos.)	32.4		
267	Plot 208A. Barley up (manure Rock Phos.)		53.7	21.3

* Soil type was Colby silt loam, Marshfield, Wis. Substation.

and one-half tons per acre. Samples 256 and 257 were from a different field, but the land had received approximately the same soil treatments as 258. None of this soil had been limed. These, together with the other results given in table 3 show that the crop had reduced the amount of calcium in the soil solution by 22.5 per cent in sample 258; 54.4 per cent in sample 260; and 39.6 per cent in sample 265. It seems evident from these results that the calcium content of the soil solution may not only be very greatly reduced during certain seasons of the year by the action of percolating water, but that a still further reduction takes place because of the absorption by a rapidly growing crop.

This effect of the crop is still further shown by the results recorded in table 4. These figures were obtained from soils kept in the greenhouse. A crop of corn was harvested from all soils on February 2, 1922. The soil from one of each pair of 2-gallon jars was removed, thoroughly mixed and a sample taken for a calcium determination on the soil solution. The duplicate jar was kept

at optimum moisture content for two months. On March 3, 1922, soybeans were harvested from other pots containing these same soils. One of each pair of duplicates was sampled and analyzed as described above, and the other was allowed to stand under optimum conditions until April 3, 1922 when all of the remaining duplicate pots from both the corn and soybean series were sampled as before and the calcium in the soil solution determined. The results of the first and second determinations are shown in table 4. With but one exception there was a decided increase in the calcium in solution after standing one or two months. Some calcium is probably made soluble from the silicates by simple hydrolysis and some is dissolved by the action of car-

TABLE 4

Effect of soil standing after crop is harvested, upon the calcium content of the soil solution

POT NO.	SOIL TYPE	FIELD TREATMENT	GREENHOUSE CROP	Ca PER ACRE IN SOIL SOLUTION		GAIN AFTER FIRST TRIAL	TIME SINCE HARVEST
				First determination	Second determination		
				lbs.	*lbs.*	*lbs.*	*months*
13–14	Carrington silt loam	General farm	Corn	33.0	82.8	49.8	2
31–32	Miami silt loam	Cropped	Corn	15.0	48.4	33.4	2
45–46	Miami silt loam	Virgin	Corn	10.0	46.4	36.4	2
65–66	Colby silt loam	Virgin	Corn	126.6	181.8	55.2	2
77–78	Colby silt loam	Manure lime	Corn	265.0	259.2	−5.8	2
89–90	Colby silt loam	Lime (1921)	Corn	163.8	191.2	27.4	2
101–102	Plainfield sand	No treatment	Corn	7.8	38.4	30.6	2
113–114	Plainfield sand	Limed	Corn	4.6	21.0	16.4	2
17–18	Carrington silt loam	General farm	Soybeans	44.4	84.0	39.6	1
57–58	Colby silt loam	No treatment	Soybeans	316.8	349.6	32.8	1
69–70	Colby silt loam	Virgin	Soybeans	91.0	170.4	79.4	1
81–82	Colby silt loam	Manure lime	Soybeans	260.6	266.6	6.0	1
Average				111.5	145.0	33.4	

Corn harvested Feb. 2, and Soybeans March 3, 1922. Second determination April 3, 1922.

bon dioxide in solution, as well as by other soil acids. It will be seen that the greatest increases were for the most part in the acid soil. A part of it may also have been due to the decay of roots from the crop which had just been harvested. The large amount of calcium in the soil solution of these greenhouse soils as compared with the field samples indicates that there is a very marked increase due to long standing under moist, warm conditions, where no leaching can take place.

STUDIES ON GREENHOUSE SOILS

A few soils kept in the greenhouse during the winter of 1921 and 1922 were not only analyzed for the total calcium and the calcium in the soil solution, but also for the amount of this element soluble in 0.2 *N* HNO_3 and

0.04 *N* carbonated water. They were also tested for acidity by the Truog test and for hydrogen-ion concentration by the colorimetric method. These soils were used chiefly as preliminary material before beginning the work with the samples from the field, but since they include some determinations not made on the field samples the results are presented for comparison.

Table 5 shows the amount of calcium of different degrees of solubility in the several soils kept in the greenhouse. The figures on the soil solution show the amount of calcium that has been already dissolved. The amount of calcium soluble in 0.04 *N* carbonated water probably includes that reported in the soil solution and nearly all the calcium in carbonate form, except in the case of limed soils where there may be some fairly large pieces of limestone which would not be completely dissolved. Some of the calcium in the form of easily soluble silicates is also dissolved by this carbonated water and changed

TABLE 5

Calcium content and acidity of different soils after being kept in the greenhouse for four months

POT NO.	SOIL TYPE	TREATMENT	TOTAL Ca PER ACRE	CALCIUM PER ACRE SOLUBLE IN			REACTION OF SOIL SOLUTION †	ACIDITY TRUOG TEST ‡
				0.2 *N* HNO_3	.04 *N* H_2CO_3	Soil solution		
			lbs.	*lbs.*	*lbs.*	*lbs.*	*pH*	
13	Carrington silt loam	None	12,460	5290	760	33.0	5.8	3
31	Miami silt loam	Cropped	13,500	4600	1000	15.0	6.6	1+
45	Miami silt loam	Virgin		4520	1000	10.0	6.3	2+
53	Colby silt loam	None	12,600	4740	930	241.4	5.6	4−
65	Colby silt loam	Virgin	14,000	2660	710	126.6	4.8	5
77	Colby silt loam	Manure, lime	15,000*	5700	1260	265.0	6.3	2+
89	Colby silt loam	Limed	13,000*	5670	1100	163.8	6.6	2+
101	Plainfield sand	None	10,900	1200	540	7.8	5.8	2+
113	Plainfield sand	Limed	12,500*	1910	896	4.6	6.6	1−

* Increase over unlimed estimated from amount of application.

† Determined by colorimetric method.

‡ 1. Very slight acidity, 2. slight, 3. medium, 4. Strong, 5. Very strong.

to a bicarbonate. It is quite significant that there is no relation between the calcium soluble in 0.04 *N* carbonated water and the amount found in the soil solution. In table 5 it may be seen that the untreated Colby silt loam showed a much higher amount of calcium in the soil solution, but a lower amount in the carbonated water extract than did the Miami silt loam. The former soil is derived mainly from granite rocks while the latter is a glacial soil and largely of limestone origin.

SOLUBLE CALCIUM AND ACIDITY OF GREENHOUSE SOILS

The relation of acidity to the amount of calcium in solution seems also to be an important factor. In the Colby silt loam the acidity was strong to very strong by the Truog test, and the hydrogen-ion concentration of the soil

solution showed a pH value of 4.8 to 5.6. The calcium in the soil solution was 241.4 pounds per acre in the check and 126.6 in the virgin soil. With the untreated Miami soils the acidity was only very slight and the pH value was 6.3 and 6.6. The calcium in solution was only 10 and 15 pounds an acre. It would seem from these data and those given in table 4 that the higher acidity of the Colby soils may be a factor in dissolving some of the calcium in the more easily soluble silicates, thus bringing it into the soil solution. It should also be noted that in all cases where the calcium in the soil solution is low the acidity is also low. It is only in the case of the Colby silt loam which has received lime that we have a high amount of calcium in solution and only a little more than slight acidity. The Plainfield sand receiving lime showed a very low amount of calcium in solution, but this can probably be accounted for by the increased demands of the crop, since the amount of calcium in solution is normally very low in this soil. Table 4 shows that after the removal of the crop the calcium in solution in this soil was materially increased. The calcium soluble in 0.04 *N* carbonated water and 0.2 *N* HNO_3 is considerably higher in all soils used in the greenhouse where lime has been applied than in the unlimed soil.

The method of making 0.2 *N* HNO_3 extractions was essentially the same as used by Ames and Gaither (2). No very good correlation was found between the calcium soluble in 0.2 *N* HNO_3 and the response to lime in the field.

CARBONATED WATER EXTRACTIONS

The second part of this study was concerned with the relation between the amount of easily soluble calcium and the returns obtained by the use of lime in the field. The chemical methods used in this work are essentially as given in an unpublished article by Professor E. Truog of the University of Wisconsin.

The calcium was determined on duplicate aliquot samples obtained by shaking 12 gm. of soil with 600 cc. of 0.04 *N* carbonated water for two hours and then filtering to obtain a clear solution.

THE RELATION OF FERTILITY AND SOLUBLE CALCIUM CONTENT TO THE USE OF LIME IN THE FIELD

It has been a common observation among farmers and experiment station men that many soils, acid by all the common tests, produce all the ordinary field crops satisfactorily and do not give large increases in crop yields following applications of lime. The reasons for this have not been well known and has often been the cause of disappointment when lime has been applied on certain acid soils. This has caused many to put less dependence than formerly in the ordinary acidity tests, especially since there has not been satisfactory agreement in the results obtained by different methods. Some have hesitated to recommend too freely the use of lime simply on the basis of acidity

determinations. There has been a general impression that the returns from lime depend somewhat on the general fertility of the land, but just how, is not definitely known.

TABLE 6

Relation of general fertility and the amount of calcium soluble in .04 N carbonated water to the response of soils to lime in the field

(Soils giving good returns for liming)

LAB. NO.	LOCATION	SOIL TYPE	ACIDITY TRUOG TEST	Ca PER ACRE SOLUBLE IN .04 *N* H_2CO_3	PLANT FOOD CONSTITUENTS PER ACRE	
					Nitrogen	Phosphorus
				lbs.	*lbs.*	*lbs.*
306, 307	St. James, Mo.	Gerald silt loam	4+	494	2765	654
298, 299	Windsor, Mo.	Oswego silt loam	4	574	2060	710
300, 301	Cuba, Mo.	Lebanon silt loam	3+	570	1630	580
302, 303	Strafford, Mo.	Lebanon silt loam	3	510	1710	620
410, 411	Union, Mo.	Union silt loam	3	540	1600*	700
350, 351	Hancock, Wis.	Plainfield sand	2+	620	785	742
360, 361	Hancock, Wis.	Plainfield sand So. Field	2+	566	785†	360
Average			3+	553	1619	624

* Average of ten analyses of this type.

† Analysis of No. 350 used.

TABLE 7

Relation of general fertility and .04 N H_2CO_3 soluble calcium content to the response of soils to liming

(Soils giving medium to small returns for lime)

LAB. NO.	LOCATION	SOIL TYPE	ACIDITY TRUOG TEST	Ca PER ACRE SOLUBLE IN .04 *N* H_2CO_3	PLANT FOOD CONSTITUENTS PER ACRE	
					Nitrogen	Phosphorus
				lbs.	*lbs.*	*lbs.*
336, 337	Janesville, Wis.	Waukesha silt loam	4+	880	5385	1480
116, 117	Maryville, Mo.	Marshall silt loam	3+	730	3965	1210
334, 335	Columbia, Mo.	Putnam silt loam	3+	830	2610	1030
332, 333	Janesville, Wis.	Waukesha silt loam	3+	820	4074	1280
416, 417	Marshfield, Wis.	Colby silt loam (202A)	3	800	4982	1448
342, 343	Coddington, Wis.	Peat	2+	2570	9820	3020
308, 309	Willow Springs, Mo.	Clarksville silt loam	2	800	1400	240
Average			3	1061	4605	1387
Average without peat soil			3+	810	3736	1114

In table 6 will be found a list of several soils that have usually given what would be called good returns for liming. That is, the results of field experiments show that it could be considered a profitable farm practice on such

lands. The results shown in these tables were obtained from the untreated plots, adjoining those that had been limed, and with which they were compared in yield. The acidity of these soils according to the Truog test; the nitrogen and phosphorus content; and the amount of calcium soluble in 0.04 *N* carbonated water are given in the table. Similar data for several soils that have given in comparative field experiments smaller returns for liming, in most cases below the cost of treatment, are given in table 7.

These figures would indicate that in the soils here considered, it is those low in potential fertility and low in easily soluble calcium that have given the most satisfactory returns for lime. It should be noted too that the average acidity of the two sets of soils is practically the same. It is the other factors that differ widely. The soils giving small returns for lime show a decidedly higher content of easily soluble calcium, 1061 pounds an acre as compared with 553 in the soils giving good returns. It would seem reasonable from this that they should act as they do in giving smaller increases for additional applications of lime than the soils which are decidedly lower in the amount of this easily soluble material.

It must not be assumed from these tables that soil acidity has no effect upon crop growth, or that the more acid portions of the same soil will produce as good crops as areas of less acidity. The fact is that the soils here reported are widely different in their physical and chemical composition. It is under conditions of this sort, that the other factors which go to make up the fertilty may overbalance to a certain extent the single factor of acidity in determining the need of different soils for lime. It is just at this point where the ordinary acidity tests fall short as a reliable method for determining in the laboratory soils where lime will be most likely to give profitable returns. Until the other physical and chemical properties, as well as the acidity of a soil are given due consideration, it will be impossible to make accurate recommendations on the basis of laboratory tests for the practical use of lime in the field.

EFFECT OF FERTILITY

In tables 6 and 7 can be seen the comparison between the nitrogen and phosphorus contents of the soils giving large and small returns for liming. It will be seen that in most cases in the soils here studied where there is a good supply of nitrogen and phosphorus the soils have not given large increases from the use of lime. In the soils listed as giving good returns for lime, only two had as much as 2000 pounds nitrogen an acre and none showed a phosphorus content of 800 pounds an acre. The Clarksville silt loam appears to be an exception to the general rule, in that it has a low nitrogen and phosphorus content and has given only small increases for lime. This can probably be explained by the fact that this soil showed 800 pounds of calcium per acre soluble in carbonated water, indicating that it was reasonably well supplied with available lime material. On the other hand, due to its very low content of nitrogen and phosphorus, it gave very marked increases for applications of nitrogenous or phosphatic fertilizers.

Several of the fertile soils studied in this work were found to be growing good red clover or alfalfa without the use of lime. These are shown in table 8 and include only soils not given in table 7, because no direct comparisons with limed soil were available and hence it was impossible to say how much these might have been benefitted by the use of liming materials. In should be remembered that practically all the soils shown in table 7 have also produced good yields of clover or alfalfa either where untreated or where fertilized with manure or phosphates. It will be seen in table 8 that the soluble calcium content of these soils is not lower than 760 pounds and in most cases well above this figure. Furthermore, these are all fairly strong soils and most of them have had some special treatment.

TABLE 8

Calcium soluble in .04 N carbonated water and acidity of soils producing good clover or alfalfa without liming

LAB. NO.	LOCATION	SOIL TYPE	SOIL TREATMENT	Ca PER ACRE SOLUBLE IN .04 *N* H_2CO_3	ACIDITY TRUOG TEST
				lbs.	
310, 311	Marshfield, Wis.	Colby silt loam	Virgin soil	940	3
316, 317	Marshfield, Wis.	Colby silt loam	Manure,	860	3
352, 353	Marshfield, Wis.	Colby silt loam	Manure, rock P.	1030	3
372, 373	Dane, Wis.	Carrington silt loam	Manure, tobacco	760	4−
324, 325	Junction City, Wis.	Colby silt loam	Manure, bone.	970	2+
344, 345	Wanakee, Wis.	Carrington silt loam	None	930	3+
362, 363	Neilsville, Wis.	Auburn loam	Old milk lot, now orchard	2870	None
374, 375	Neilsville, Wis.	Colby silt loam (rolling phase)	Manured, near barn	1080	2+

While it is not thought possible at the present time and with the limited amount of data, to say that a definite quantity of calcium soluble by this method is necessary for the most profitable growth of crops, there have been found no soils in this work having more than approximately 700 pounds of calcium soluble in 0.04 *N* carbonated water that have indicated by field tests a serious need for lime. On the other hand, all the soils studied that have been decidedly lower than this amount of soluble calcium have in most cases shown a fairly good return for liming. This point, however, needs further investigation, for it is likely that different classes or types of soils may show marked differences in the necessary calcium supply, especially when the general fertility is considered.

VARIATION IN SOLUBLE CALCIUM CONTENT IN SOILS OF APPROXIMATELY THE SAME ACIDITY

That soils of approximately the same acidity may vary widely in their content of total calcium or calcium soluble in normal and 0.2 *N* HCl has been shown by Swanson, Latshaw and Tague (22). A similar variation was found in the present work with 0.04 *N* carbonated water.

The range of variation in the soluble calcium content of different soils or soils having different treatments but showing similar degrees of acidity is given in table 9.

The soils reported in this table include those from widely different types of Wisconsin and Missouri soils. In addition many of the soils had received different soil treatments, such as manure, fertilizer or lime.

Some soils in each group used in this study had as little calcium soluble in 0.04 *N* carbonated water as approximately 500 pounds an acre. The maximum was much more variable, being 880 pounds in the strongly acid soils and 2920 pounds in one of the peat soils sowing slight acidity and which had

TABLE 9

Variation in the amounts of calcium soluble in .04 N carbonated water in soils having approximately the same degree of acidity

NUMBER OF SOILS ANALYZED	ACIDITY TRUOG TEST	RANGE IN SOLUBLE Ca PER ACRE
		lbs.
11	Strong	494 to 880
19	Medium	510 to 1030
14	Slight	566 to 2920
10	Very slight	500 to 2870

been limed. It should be said, however, that only two unlimed soils showed more than 1150 pounds calcium soluble in 0.04 *N* carbonated water. One of these was a peat and the other Auburn loam from an old milk lot.

It was found in each group of soils, based on the degree of acidity, that it has been the soils with low amounts of soluble calcium that have shown the greatest need for applications of lime in the field. This fact was previously brought out in the report on the untreated soils shown in tables 6 and 7.

The results obtained on the soils reported in this paper would seem to indicate that, with any degree of acidity, soils having a low amount of calcium soluble in 0.04 *N* carbonated water may reasonably be expected to give at least favorable results from applications of lime. On the other hand, if a soil has a large supply of soluble calcium it is highly probable that additional applications of liming materials will be only very slightly beneficial and from a practical standpoint the cost may often overbalance the increased returns from the crops. Where the phosphorus content is low and there is a fairly good supply of soluble calcium it is likely that additions of phosphorus will be more beneficial than applications of lime.

EFFECTIVENESS OF CARBONATED WATER AS A SOLVENT

The effect of carbonated water as a solvent is shown by comparing the amount dissolved by this method with the total calcium content of a number of soils. Table 10 shows that as an average of seventeen soils, 9.32 per cent of the total calcium was dissolved by carbonated water, while the per cent soluble ranged from 4.21 in one sample of Carrington silt loam to 37.33 in the Vesper sandy loam. These figures compare very well with Shedd's results (20), as he found from 3.8–10.6 per cent of the total calcium of Kentucky soils soluble in carbonated water.

TABLE 10

Total magnesium and calcium compared with the calcium soluble in .04 N carbonated water

LOCATION (WISCONSIN)	SOIL TYPE	TOTAL Mg*	TOTAL Ca*	Ca SOLUBLE IN .04 *N* H_2CO_3	Ca SOLUBLE IN .04 *N* H_2CO_3
		per cent	*per cent*	*per cent*	*per cent (of total Ca)*
Coddington	Peat	0.28	1.715	0.1285	7.48
Morrisonville	Carrington silt loam	0.33	0.83	0.035	4.21
Marshfield	Colby silt loam, virgin	0.41	0.70	0.047	6.71
Marshfield	Colby silt loam, 102A	0.41	0.63	0.0575	9.12
Wanakee	Carrington silt loam	0.52	0.63	0.046	7.30
Marshfield	Colby silt loam (new farm)	0.43	0.62	0.043	6.93
Marshfield	Colby silt loam 202A	0.41	0.61	0.040	6.55
Neilsville	Colby silt loam (rolling)	0.38	0.59	0.0445	7.50
Janesville	Waukesha silt loam (County farm)	0.41	0.57	0.041	7.19
Junction City	Colby silt loam	0.40	0.56	0.0485	8.66
Janesville	Waukesha silt loam (Hughes Farm)	0.47	0.545	0.044	8.07
Hancock	Plainfield sand	0.04	0.545	0.0345	6.33
Dane	Carrington silt loam	0.375	0.525	0.038	7.23
Dane	Carrington silt loam	0.37	0.515	0.035	6.79
Stockton	Plainfield sandy loam	0.21	0.415	0.0355	8.55
Plover	Waukesha sand	0.09	0.205	0.0255	12.43
Neilsville	Vesper fine sandy loam	0.04	0.075	0.028	37.33

* Determinations of total Mg and Ca were made by Mr. M. Tosterud, in the Soils Laboratory of the University of Wisconsin.

That the carbonated water extract will indicate the lime need more accurately than the determination of the total calcium is indicated in a few cases in this table. For instance the Plainfield sand has a rather high amount of calcium, while the soluble calcium is relatively low. Experiments have shown that the soil responds fairly well to lime, particularly with alfalfa. In the case of Colby silt loam at Marshfield, plot 202A has given somewhat better increases for liming than 102A which has a much higher soluble calcium content, but the total amounts of calcium differ by only 0.02 per cent. Acidity tests also show 102A to be somewhat less acid.

SUMMARY

The work reported in this paper has not been in progress long enough, nor has it included a sufficient number of soils to permit drawing definite conclusions, but the principal points studied are as follows:

1. A study was made between the amounts of calcium in different forms in soils and the results obtained in the field from applications of lime. Comparisons were made with the results of ordinary acidity determinations. Determinations were made on the soil solution obtained by the displacement method.

2. In nearly all cases liming increased the amount of calcium in the displaced soil solution. The few instances where this was not the case can probably be explained by the fact that the increased growth of clover had absorbed more of this element from the limed land.

3. The calcium content of the soil solution was reduced 22–54 per cent by the presence of a clover crop on the Colby silt loam.

4. Soils kept in the greenhouse showed great variation in the calcium content of the displaced solution as compared with field samples taken in the spring. The calcium in the soil solution was greatly increased in the strongly acid Colby silt loam when kept under greenhouse conditions for a period of six months.

5. Soils allowed to stand in the greenhouse after the crop was removed showed a rapid increase in the calcium content of the soil solution. This was probably due largely to hydrolysis and to the dissolving action of carbon dioxide in solution as well as by other soil acids.

6. No very definite correlation was found between the calcium in the soil solution and the need for lime in the field. There are so many factors which cause this calcium content to vary, that it changes greatly from season to season.

7. Soils which had given good returns for lime in the field were compared with soils on which the returns for lime had been medium to poor. It was found that the average acidity of the two sets was about the same according to the Truog test. Determinations showed, however, that the calcium soluble in 0.04 *N* carbonated water averaged only 553 pounds an acre on the soils giving marked increases for lime and 810 pounds an acre on soils giving small returns for applications of liming materials.

8. It was further noted that marked increases due to liming were mainly on infertile soils. That is, they averaged but 1619 pounds nitrogen and 624 pounds phosphorus an acre. The mineral soils giving small returns for lime averaged 3736 pounds nitrogen and 1114 pounds phosphorus per acre. The analysis of the peat soil brought the average considerably above these figures.

9. It would seem from these results that if a soil is well supplied with nitrogen, phosphorus, and a fair amount of calcium soluble in carbonated water, is will likely produce good yields of the common field crops in spite of a considerable amount of soil acidity.

10. In case one of the elements of fertility is greatly lacking and the calcium soluble in carbonated water is reasonably high, as was true on the Clarksville silt loam, the addition of phosphorus or other deficient element may give far greater returns than the application of limestone.

11. Soils of approximately the same acidity may vary widely in their amount of calcium soluble in carbonated water. All the soils studied regardless of treatment were arranged in groups according to their acidity. It was found that soils showing strong acidity varied in their soluble calcium content of 494–880 pounds per acre; those of medium acidity 510–1030 pounds; those of slight acidity 566–2920 pounds; and those of very slight acidity 500–2870 pounds per acre.

12. When the return per ton of limestone was considered it was found to show a closer relation in different soils to the amount of calcium soluble in 0.04 *N* carbonated water than to the degree of soil acidity. That is, where there was a low amount of soluble calcium there was usually a greater return for liming than where there was already a large amount of calcium present that could be dissolved in this weak acid.

13. The carbonated water extracted on the average 9.32 per cent of the total calcium in the soils studied.

14. Further work is being carried out on this problem to determine more definitely the concentration of carbonated water, the time of extraction, and methods of drying and preparing the samples that will give results showing the best correlation with the effects of soil treatments in the field. Studies are also being made on the calcium content of subsoils and its relation to the conditions to be found in the surface layer.

REFERENCES

(1) AMES, J. W. 1921 Solvent action of nitrification and sulfofication. Ohio. Agr. Exp. Sta. Bul. 351, p. 251.

(2) Ames, J. W., and Gaither, E. W. 1913 Composition of calcareous and non-calcareous soils. Ohio. Agr. Exp. Sta. Bul. 261.

(3) AMES, J. W., AND SCHOLLENBERGER, C. J. 1919 Calcium and magnesium content of virgin and cultivated soils. *In* Soil Sci., 8, p. 323–335.

(4) BRYAN, O. C. 1923 Effect of reaction on growth, nodule formation, and calcium content of alfalfa, alsike clover and red clover. *In* Soil Sci., v. 15, no. 1, p. 23–30.

(5) CONNER, S. D. 1921 Liming in its relation to injurious inorganic compounds in the soil. *In* Jour. Amer. Soc. Agron., v. 13, no. 3, p. 113–123.

(6) ENGELS, O. 1912 Die Wirkung einiger Lösungsmittel auf die im Boden enthaltenen Pflanzennährstoffe, Phosphorsaure, Kali und Kalk im ursprunglichen und absorptiv. gebundenen Zustande. *In* Landw. Vers. Stat. v. 77, p. 269–304.

(7) HARTWELL, B. L., AND PEMBER, F. R. 1920 The effect of dicalcium silicate on an acid soil. *In* Soil Sci., v. 10, p. 57–60.

(8) HOAGLAND, D. R. 1918 The freezing point method as an index of variations in the soil solution due to season and crop growth. *In* Jour. Agr. Res., v. 12, no. 6, 369–395.

(9) HOAGLAND, D. R. 1920 Relation of the concentration and reaction of the nutrient medium to the growth and absorption of the plant. *In* Jour. Agr. Res., v. 18, p. 73–117.

(10) HOLLEMAN, A. F. 1892 Über die Bekalkung von steifen Kleyboden. *In* Landw. Vers. Stat., v. 41, p. 37–41.

(11) MACINTIRE, W. H., AND WILLIS, L. G. 1914 Comparison of silicates and carbonates as sources of lime and magnesium for plants. *In* Jour. Indus. Engin. Chem., v. 6, p. 1005–1008.

(12) MASCHHAUPT, J. G., AND SINNIGE, L. R. 1912 Determination of the value of plant food constituents in soils and fertilizers as dependent upon solubility. *In* Exp. sta. Rec., v. 27, p. 515.

(13) MCCALL, A. G. 1923 The influence of acidity itself on plant growth without regard to other factors. *In* Jour. Amer. Soc. Agron., v. 15, no. 77, p. 295–297.

(14) MCCOOL, M. M., AND MILLAR, C. E. 1918 Soluble salt content of soils and some factors affecting it. Mich. Agr. Exp. Sta. Tech. Bul. 43.

(15) MIETH, HANS. 1910 Ist der Kalk des kieselsauren Kalkes zur Ernährung der Pflanze geeignet? *In* Landw. Vers. Stat., v. 74, p. 81–120.

(16) MITSCHERLICH, E. A. 1907 Eine chemische Bodenanalyse Pflanzenphysiologische Forschungen. *In* Landw. Jahr. v. 36. p. 309–369.

(17) MUSBACH, F. L. 1922 Farming the silt loams of central Wisconsin. Wis. Agr. Exp. Sta. Bul. 347.

(18) PARKER, F. W. 1921 Methods of studying the concentration and composition of the soil solution. *In* Soil Sci., v. 12, no. 3, p. 209–232.

(19) PLUMMER, J. K. 1914 Relation of the mineralogical and chemical composition to fertilizer requirements of North Carolina soils. N. Car. Agr. Exp. Sta. Tech. Bul. 9.

(20) SHEDD, O. M. 1921 A comparison of the calcium content of some virgin and cultivated soils of Kentucky by an improved method for the estimation of this element. Ky. Agr. Exp. Sta. Bul. 236.

(21) SHOREY, E. C., FRY, W. H., AND HAZEN, W. 1917 Calcium compounds in soils. *In* Jour. Agr. Res., v. 13, p. 57–77.

(22) SWANSON, C. D., LATSHAW, W. L., AND TAGUE, B. L. 1921 Relations of the calcium content of some Kansas soils to the reaction as determined by the electrometric titration. *In* Jour. Agr. Res., v. 20, p. 855–868.

(23) TRUE, R. H. 1921 The function of calcium in the nutrition of seedlings. *In* Jour. Amer. Soc. Agron., v. 13, p. 91–107.

(24) TRUE, R. H. 1921 The significance of calcium for higher green plants. *In* Science, n.s., v. 55, no. 1410, p. 1–6.

(25) TRUOG, E. 1916 The utilization of phosphates by agricultural crops. Wis. Agr. Exp. Sta. Res. Bul. 41.

(26) TRUOG, E. 1918 Soil Acidity: 1. Its relation to the growth of plants. *In* Soil Sci., v. 5., p. 169–195.

(27) TRUOG, E. 1920 Testing soils for acidity. Wis. Agr. Exp. Sta. Bul. 312.

(28) WHITE, J. W. 1904 Concerning the growth and composition of clover and sorrel as influenced by varied amounts of limestone. *In* Ann. Rpt. Penn. Sta. Coll. 1913–14, 46–64.

(29) WOLFF, EMIL 1871 Aschen analysen. Berlin.

CARBON DIOXIDE PRODUCTION OF PLANT ROOTS AS A FACTOR IN THE FEEDING POWER OF PLANTS[1]

F. W. PARKER

Alabama Polytechnic Institute

Received for publication December 17, 1923

It is well known that plants differ widely in their composition with respect to the essential elements secured from the soil. That this is the case is shown by a compilation of data from a large number of different sources (8). The objection has been made (7) that the results were obtained from plants grown on a number of different soils whose composition and fertility are unknown, and that therefore the differences may not be reliable.

The composition and fertility of the soil undoubtedly have considerable influence on the composition of the plant. However, several workers (6, 7, 9, 14, 16) have shown that when different species of plants are grown on the same soil they differ in composition. These differences are ordinarily attributed to differences in the feeding power of the plants. Undoubtedly the feeding power of a plant is affected by many factors, but the relative importance of these factors is not clearly understood at present.

At one time it was believed that the feeding power of plants was due to the excretion of acids from the plant roots. Later it was shown that carbon dioxide was the only acid excreted in significant quantities and that all plants excrete carbon dioxide from their roots. It has been generally recognized that the carbon dioxide given off by the plant roots would have a solvent effect on the soil minerals, thereby increasing their availability to the plant. The importance of this solvent action is not definitely known, and there is some doubt as to whether or not differences in the feeding power of plants can be attributed to differences in carbon dioxide production. This paper presents some of the results secured in an investigation that is being made to determine (*a*) whether or not the excretion of carbon dioxide from plant roots is an important factor in the feeding power of plants; and (*b*) whether or not differences in the feeding power of plants can be attributed to differences in the amount of carbon dioxide excreted from the roots.

A good review of the literature on the importance of the carbon dioxide of the soil air is given by Turpin (13). He also discusses the influence of different factors, including the crop, on the amount of carbon dioxide in the soil air. Therefore, an extensive review of the literature on the subject is unnecessary. Only the more important papers bearing directly upon the problem will be considered.

Stoklasa and Ernest (15) have shown that the amount of phosphorus and potassium absorbed from gneiss and basalt by different plants is proportional to the carbon dioxide produced per gram of dry matter of the roots. Aberson (1) working with young plants concluded that the carbon dioxide excreted by plants was sufficient to bring into solution insoluble soil minerals, especially phosphates. Pfeiffer and Blanck (9) studied the assimilation of phosphorus from soil cultures, fertilized with different phosphates, which were saturated with carbon dioxide three times a week. They found that the carbon dioxide treatment was

[1] Published with the permission of the Director of the Alabama Experiment Station.

The writer wishes to express his appreciation to Prof. M. J. Funchess for the helpful suggestions and criticism tendered during the course of the investigation.

favorable when used with soluble phosphates, but with insoluble phosphates it was not beneficial. They also found that lupines and peas absorbed more phosphorus than oats and that the carbon dioxide treatments did not change this relation.

Newton (7) in a study of the absorption of elements by barley and peas found that absorption was practically the same when nutrient solutions were used. When grown in soil cultures the peas absorbed larger amounts of calcium, magnesium, nitrogen and phosphorus. He attributes this difference in absorption in the soil to a difference in the amount of carbon dioxide excreted by the plant roots. Studies on carbon dioxide production in sand cultures showed that the roots of peas gave off approximately twice as much carbon dioxide in a given period of time as did the roots of barley.

Truog (11, 12) does not consider differences in carbon dioxide production as a satisfactory explanation of the differences in the feeding power of plants. He explains differences in the feeding power of plants for calcium, potassium, and phosphorus in rock phosphate on the basis of the law of mass action and chemical equilibrium. The acidity of the plant sap is considered as one of the most important factors affecting the equilibrium and consequently the feeding power of the plant.

Davis, Hoagland and Lipman (5) criticise the theory of Truog. Basing part of their argument on the results of Newton (7), they attribute considerable importance to the extent of the root system and to the excretion of carbon dioxide from the plant roots.

DISCUSSION OF EXPERIMENTAL METHODS

Two general methods have been used in these experiments to study the importance of carbon dioxide production as a factor in the feeding power of plants. In the first method the carbon dioxide production of a number of different plants grown in soil cultures was studied throughout the growing period. As was to be expected, considerable differences in carbon dioxide production were found among the different plants. When the plants reached the blooming stage, they were harvested and analyzed to determine their composition with respect to several of the essential elements. Large and apparently characteristic differences were found in plant composition. The two sets of data were then studied to determine whether or not the differences in composition could be attributed to differences in the amount of carbon dioxide excreted from the plant roots.

The carbon dioxide production of the plant roots was studied in three different ways. (1) The percentage of carbon dioxide in the soil air was determined at frequent intervals, usually twice a week. (2) The amount of carbon dioxide produced in a period of six hours was determined by drawing a definite volume of air through the culture and absorbing the carbon dioxide. This determination was made once each week during the growing period. (3) In one experiment the total amount of carbon dioxide given off during the growing period was determined. Plants were grown in sealed cultures which were aspirated, the carbon dioxide absorbed and measured each day.

In the second general method used in the investigation, the carbon dioxide was removed from the cultures by continuous aspiration. In this manner the carbon dioxide content of the soil air was reduced to 0.20 per cent or less. The aspiration would certainly hasten the removal of carbon dioxide from

around the root hairs and thus reduce the importance of carbon dioxide as a factor determining the amount of the different elements absorbed by the plant. Obviously it is impossible to completely remove carbon dioxide as a factor in this manner. However, rapid, continuous aspiration should reduce its influence and should affect the composition of the plant if carbon dioxide production is a determining factor in the feeding power of plants.

In addition to these methods of studying the problem, use was made of sand cultures. Different plants were grown in sand cultures with nutrient solutions. Absorption was studied by determining the composition of the plants. In such cultures carbon dioxide production should not influence absorption, since all the essential elements are in solution. A difference in composition would therefore indicate that one or more factors other than carbon dioxide production was responsible for the difference in absorption.

More detailed descriptions of the methods used will be given when the different experiments are considered.

Standard methods of analysis were used in determining the composition of the plant.

EXPERIMENT I

The purpose of this experiment was to determine whether or not there was a correlation between the carbon dioxide production of different plants and their feeding power. Carbon dioxide production was measured by determining the percentage of carbon dioxide in the soil air at intervals during the growing period. The feeding power of the plant is indicated by its composition with respect to the various elements.

Velvet beans, buckwheat, sorghum, cowpeas and soybeans were grown in two gallon soil cultures. The soil was a slightly acid sandy loam of medium fertility, nitrogen being the element limiting the growth of non-leguminous crops. Nitrate of soda was applied to the buckwheat and sorghum cultures as soon as it became evident that a lack of nitrates was limiting their growth. The buckwheat received one gram of $NaNO_3$ twenty-seven days after planting. The sorghum received one gram twenty-seven days after planting and another gram twenty days later. All cultures were watered with distilled water.

The plants were grown until they were in bloom except in the case of velvet beans. The latter made an excellent growth, but did not bloom. There were four plants in each two gallon culture except in the case of buckwheat where there were eight plants per culture. All cultures were in duplicate and the figures given for composition and carbon dioxide production are the averages.

The carbon dioxide content of the soil air was determined by the following procedure:

The 2-gallon glazed earthenware culture vessles were provided with a drainage hole near the bottom. A piece of glass tubing extended from the center of the jar near the bottom, through a paraffined cork stopper, to the outside. A sample of the soil air could readily be obtained by drawing it out through this tube. To obtain and analyze a uniform sample, a definite amount of 0.1*N* $Ba(OH)_2$ was introduced into a 500-cc. filter flask. Immediately after the introduction of the $Ba(OH)_2$, the flask was stoppered and connected with a strong filter pump for two minutes. This almost completely evacuated the flask. A stopcock on the side tube was closed, and the flask connected with the glass tube extending into the soil culture. Upon opening the stopcock the soil air was drawn into the flask. The stopcock was

then closed, the flask shaken to absorb all carbon dioxide and the excess of $Ba(OH)_2$ was titrated with HCl. The temperature and barometric pressure were determined and the proper correction applied.

This method of sampling and analyzing the soil air is accurate and rapid. The results are easily duplicated if the proper precautions are used. It is essential that the evacuation should be uniform so that all samples are of the same size. Frequent determinations of the degree of evacuation and size of sample are necessary to insure uniformity. It is necessary to have the moisture content of the culture uniform. If the culture dries out somewhat, the carbon dioxide will diffuse out more readily and much lower results will be secured than in the case of a similar culture with a higher moisture content.

Experimental results have been secured which show that carbon dioxide production is greater at certain times of the day than at others, the maximum production being in the early part of the afternoon. Accordingly all determinations of the carbon dioxide content of the soil air should be made at the same time of day. This was done in experiment 2. In experiment 1, some

TABLE 1

Carbon dioxide content of the soil air under different crops

AGE OF PLANTS	NUMBER OF DETERMINATIONS IN PERIOD	VELVET BEANS	BUCKWHEAT	SORGHUM	COWPEAS	SOYBEANS	NO CROP
days		*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*
1–14	2	0.19	0.17	0.19	0.19	0.17	0.19
15–28	4	0.80	0.40	0.67	0.99	0.54	0.19
29–42	4	2.51	1.08*	2.03	2.28	1.78	0.21
43–56	3	2.74	....	1.27	2.83	2.11	0.18
57–70	3	2.74	....	2.49	2.91*	1.69	0.16
Maximum percentage.		3.94	1.58	3.30	4.32	2.70	0.24

* Average of two determinations.

of the determinations were made in the morning, and others in the afternoon. However, the determinations on all cultures for a given day were made at approximately the same time so the results are comparable.

The results for carbon dioxide production are shown in table 1. All crops caused a large increase in the carbon dioxide content of the soil air. The greatest increase was caused by cowpeas and velvet beans. The smallest increase and therefore the smallest excretion of carbon dioxide from the plant roots was found in the buckwheat cultures. Sorghum and soybeans produced about the same increase, the former causing a slightly greater increase in the carbon dioxide content of the soil air.

Table 2 gives the age, yield and analysis of the different crops. The analysis is given on the percentage basis which is considered preferable to calculating the total amount of the different elements removed by the crop. The latter may be calculated from the table and will be considered in the discussion of the results.

The data in table 2 make possible some very interesting comparisons between the different crops. Sorghum and cowpeas were harvested at almost the same time. The dry weights are identical and yet their analyses are widely different. The cowpeas had an ash content more than double that of the sorghum, the calcium content was 364 per cent greater, the magnesium content approximately double, and the nitrogen content 261 per cent greater than that of sorghum. Evidently there is a great difference in the feeding power of the two plants. A study of the results for carbon dioxide production shows that the plants are not widely different in this respect. Cowpeas at all times produced a slightly higher percentage of carbon dioxide in the soil air than did sorghum. It does not seem probable that this difference in carbon dioxide production is great enough to account for their difference in feeding power.

Buckwheat and sorghum also afford an interesting comparison of crops with radically different feeding powers. Sorghum had a growing period twice as long as did the buckwheat. It produced twice as much dry weight. However, analysis shows that the ash content of the buckwheat was 309 per

TABLE 2

The yield and percentage (dry weight) composition of different crops grown in soil cultures

CROP	AGE AT HARVEST	WEIGHT OF DRY TOPS	ASH	Ca	Mg	P	N
	days	*gm.*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*
Velvet beans	96	42.15	4.63	1.07	0.29	0.11	1.54
Buckwheat	35	6.12	11.55	1.86	0.54	0.44	2.29
Sorghum	68	12.25	3.73	0.39	0.21	0.18	1.08
Cowpeas	64	12.17	8.77	1.42	0.39	0.22	2.82
Soybeans	88	22.50	4.45	0.71	0.33	0.16	2.06

cent higher, the calcium content 476 per cent higher, the magnesium content 257 per cent higher, the phosphorus content 244 per cent higher and the nitrogen content 212 per cent greater than that of sorghum. If the total amount of the different constituents taken up by the plants is calculated, it will be found that in every case buckwheat absorbed more than did sorghum. The percentage increase in total amount absorbed is obtained by subtracting 200 from the figures given above.

That this great difference in the feeding power of the two plants is not due to a difference in carbon dioxide production is evident from a study of table 1. Buckwheat has a very limited root system and carbon dioxide production is very limited. Sorghum has a very extensive root system and produces considerable quantities of carbon dioxide. The difference in the feeding power of the two crops cannot be attributed to differences in the extent of the root system or to differences in carbon dioxide production. It must be due to some other factor or group of factors. The high acidity of the buckwheat sap (12) may be a partial explanation of the difference.

Soybeans and sorghum were similar in carbon dioxide production as indicated in table 1. Soybeans had a considerably higher percentage of ash, calcium, magnesium and nitrogen. A comparison of the total amount of the different elements absorbed shows that the soybeans absorbed very much larger amounts of all elements than did the sorghum. Sorghum produced slightly larger amounts of carbon dioxide and consequently it is impossible to explain the results on the basis of differences in carbon dioxide production.

Further comparisons might be made from the results set forth in tables 1 and 2. However, in no case is there good evidence that differences in the feeding power of the plants can be attributed to differences in carbon dioxide production from the plant roots.

EXPERIMENT 2

One object of this experiment was a verification of the results secured in the preceding experiment. A second object was to determine what effect removing carbon dioxide from the culture would have on the feeding power of the plant as indicated by its composition.

The cultures were grown in two series. Series 1 was not aspirated and the carbon dioxide content of the soil air was determined twice a week. Series 2 received rapid, continuous aspiration during the entire growing period. All cultures were in 4-gallon glazed earthenware jars provided with a glass tube near the bottom as described in experiment 1. The soil was a rather poor, slightly acid Norfolk sandy loam from the experiment station farm. The crops and fertilizer treatment are indicated in table 3. Sodium nitrate was applied at the rate of three grams per culture at the time of planting. The cowpeas and soybeans were grown with and without the application of the nitrate. This seemed desirable as the fertilization might influence the composition to a considerable extent. All cultures were in duplicate, with five plants per culture except with buckwheat which had ten plants and cotton which had three plants per culture.

Table 3 shows the carbon dioxide content of the soil air in series 1 during successive 7-day periods. Figure 1 shows the same results except that the individual determinations are plotted instead of the average for the week. The results for the cowpeas and soybeans which did not receive sodium nitrate are not shown in figure 1. The fertilization of these crops caused a greater and more rapid growth and increased carbon dioxide production.

The results show that cowpeas excrete more carbon dioxide than any of the other crops. Soybeans, sorghum and cotton are similar with respect to their influence on the carbon dioxide content of the soil air. As in experiment 1, soybeans and sorghum gave nearly the same result. Cotton, a plant which will make a satisfactory growth on poorer soils than will soybeans or sorghum, produced less carbon dioxide than either of the latter. Buckwheat roots gave off very little carbon dioxide. These results agree very well with those secured in experiment 1, the chief difference being that the cowpeas in experiment 2 evidently gave off more carbon dioxide than the cowpeas in experiment 1. This difference is not great when the com-

parison is made with the cowpea cultures which did not receive sodium nitrate.

The carbon dioxide production of these crops was also measured by the aspiration method. In this method the cultures of series 2 receiving continuous aspiration were used. The cultures were aspirated at the rate of 6000 cc. per hour for six hours. The air from the culture was drawn through a Truog carbon dioxide absorption apparatus (10) where the carbon dioxide

TABLE 3

*Carbon dioxide content of the soil air under different crops**

AGE OF PLANTS	SORGHUM	COWPEAS	BUCK-WHEAT	SOYBEANS	COTTON	COWPEAS NO $NaNO_3$	SOYBEANS NO $NaNO_3$	NO CROP
days	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*
15–21	0.79	1.26	0.82	0.88	0.84	1.14	0.86	0.65
22–28	0.86	1.83	0.84	1.15	1.01	1.67	0.91	0.46
29–35	1.26	3.20	0.79	1.40	1.25	2.39	1.14	0.39
36–42	1.68	5.11	....	2.34	1.85	3.71	1.20	0.25
43–49	1.60	3.27	....	1.76	1.38	2.58	0.96	0.14
50–56	2.59	3.43	....	2.20	1.85	3.20	1.70	0.20
57–63	2.51	2.69	....	2.04	1.85	2.78	1.95	0.13

* Figures are the average of duplicate determinations made on two different days.

TABLE 4

Carbon dioxide obtained from soil cultures of different crops by the aspiration method

AGE OF PLANTS	SORGHUM	COWPEAS	BUCK-WHEAT	SOYBEANS	COTTON	COWPEAS NO $NaNO_3$	SOYBEANS NO $NaNO_3$	NO CROP
days	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*
16	0.09	0.14	0.12	0.12	0.10	0.15	0.12	0.09
23	0.13	0.22	0.16	0.17	0.14	0.25	0.19	0.07
30	0.17	0.45	0.13	0.24	0.24	0.38	0.22	0.07
37	0.21	0.48	....	0.26	0.21	0.39	0.16	0.06
44	0.16	0.36	....	0.17	0.17	0.26	0.15	0.04
51	0.24	0.42	....	0.24	0.17	0.32	0.22	0.04
58	0.28	0.39	....	0.22	0.18	0.37	0.28	0.04
Total.....	1.28	2.46	0.41	1.42	1.21	2.12	1.34	0.41
Average....	0.18	0.35	0.14	0.21	0.17	0.30	0.20	0.06

was absorbed in 0.4 *N* $Ba(OH)_2$. When aspiration was stopped the excess $Ba(OH)_2$ was titrated with HCl and the grams of carbon dioxide obtained from the culture were calculated. The determinations were made weekly and the results shown in table 4 are for single determinations. This method gives results very similar to those obtained by the sample method, shown in table 3. Cowpea roots give off the most carbon dioxide. Soybeans, sorghum and cotton rank in the order named, but the differences between them are small. Buckwheat ranks far below the other crops in carbon dioxide production.

The buckwheat was harvested thirty-five days after planting, when it was in full bloom. All other crops were harvested at the end of sixty days as they were all in bloom, except cotton. The cotton had made a good growth and had from two to three squares per plant. Table 5 gives the age, dry weight and analysis of the crops from the non-aspirated cultures, series 1.

Cotton and sorghum were similar in carbon dioxide production but sorghum undoubtedly has a more extensive root system than cotton which is a tap-

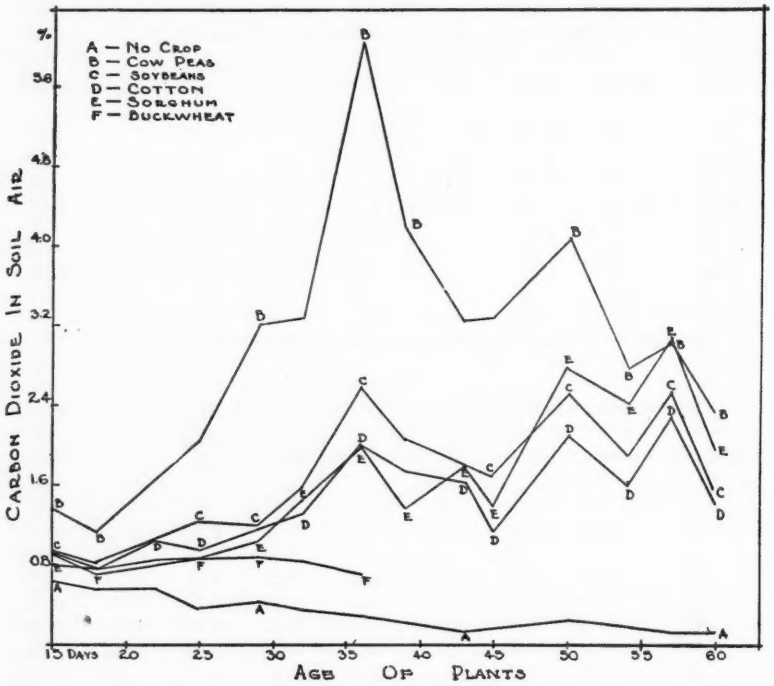


Fig. 1. Percentage of Carbon Dioxide in the Soil Air of Cultures of Different Plants

rooted plant. From a consideration of those two factors one would conclude that sorghum would have the greater feeding power. The analysis shows, however, that the cotton plant has more than double the ash content of sorghum. The calcium content is practically four times as great and the magnesium, potassium, phosphorus and nitrogen content of the cotton is considerably higher than that of sorghum.

If the comparison is made on the basis of the total amount absorbed the relation is not changed materially. It is evident therefore that the difference in feeding power cannot be attributed to differences in carbon dioxide production or extent of the root system.

The sorghum and the soybeans receiving nitrate of soda produced nearly the same amount of carbon dioxide and their dry weights are almost identical. The soybeans contained a higher percentage of all elements for which analysis was made. The difference was greatest in the case of the percentage of ash, calcium and nitrogen.

Buckwheat, with a small root system and producing a small amount of carbon dioxide, contained a much higher percentage of all constituents than did sorghum. Considering the amounts absorbed there would be very little difference between the two plants. It seems probable that the high feeding power of buckwheat may be due to the high acidity of its cell sap as suggested by Truog (12). It should be noted, however, that the buckwheat contained a very high percentage of potassium, more than double that of any other crop except cotton. The buckwheat in its short growing period, and making

TABLE 5

The yield and percentage (dry weight) composition of different crops grown in four gallon soil cultures

CROP	AGE AT HARVEST	WEIGHT OF DRY TOPS	ASH	Ca	Mg	K	P	N
	days	*gm.*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*
Sorghum.....	60	28.45	3.85	0.53	0.36	0.88	0.12	1.46
Cotton.....	60	20.20	9.14	2.00	0.49	1.22	0.21	2.20
Buckwheat...	35	12.20	8.76	1.00	0.79	2.33	0.12	2.36
Cowpeas.....	60	40.40	6.01	1.24	0.39	0.89	0.12	2.39
Soybeans.....	60	27.60	6.43	1.40	0.45	1.03	0.16	2.19
Cowpeas*....	60	25.50	6.45	1.34	0.43	0.92	0.13	2.37
Soybeans*....	60	22.75	6.47	1.31	0.39	1.12	0.16	2.47

* Were not fertilized with $NaNO_3$.

a small dry weight, took up more potassium than any other culture except the cowpeas which received sodium nitrate. This result is in apparent disagreement with the statement of Truog (12) that buckwheat is a poor feeder on mineral potash. Additional experimental evidence must be secured to determine the potassium requirement of buckwheat, and to determine its feeding power for potassium as compared to that of other plants.

The greatest production of carbon dioxide was in the cowpea cultures fertilized with nitrate. These plants contained a smaller percentage of all mineral constituents than did cotton or soybeans receiving the same fertilization. However, due to the fact that they made a greater growth, the fertilized cowpeas absorbed a larger amount of the different elements than did any other culture. This is in accordance with the amount of carbon dioxide produced. However, if comparison is made with sorghum or soybeans the increase in the amount of the different elements absorbed is not proportional to the increase in carbon dioxide production.

Fertilization with sodium nitrate increased the dry weight and carbon dioxide production of cowpeas and soybeans, but it did not have an appreciable effect on the percentage composition of the plants. Even the nitrogen content was not increased.

The results of this experiment serve to verify those obtained in the first experiment. In neither case was evidence obtained which would indicate that the carbon dioxide production of plant roots was associated with the feeding power of the plants.

THE INFLUENCE OF CONTINUOUS ASPIRATION ON THE FEEDING POWER OF THE PLANT AS INDICATED BY ITS COMPOSITION

As has been indicated, the cultures in series 2 were identical in all respects to those for which data have just been given, except that they received continuous aspiration, the purpose being to remove carbon dioxide as a factor influencing the feeding power of the plant. Aspiration was continuous throughout the growing period. The average rate of aspiration was approximately twenty-five to thirty liters per hour. This was produced by connecting all the cultures with a strong filter pump. Several times during the growing period the carbon dioxide content of the soil air was determined. The maximum percentage found in any culture was 0.24 per cent. The average of all determinations was 0.16 per cent. As has been shown in table 3 the carbon dioxide content of the air in the non-aspirated cultures was seldom less than 1.50 per cent, and was frequently as high as 2.00 or 3.50 per cent. Therefore, the method was effective in removing most of the carbon dioxide from the culture.

There are certain objections to the method. The thorough aeration would increase bacterial activities such as nitrification. This is not considered a serious objection as aeration in the sandy soil was very good in the non-aspirated cultures. Also the application of three grams of sodium nitrate per culture would tent to prevent increased nitrification from influencing growth and absorption of the plant.

The most serious objection is that the carbon dioxide was not completely removed. The root surfaces are in such intimate contact with the soil particles that the solvent action of the carbon dioxide would take place before the removal of the carbon dioxide. This is undoubtedly true to a certain extent. Nevertheless the rapid aspiration would certainly hasten diffusion from these surfaces and reduce the solvent action of the carbon dioxide. It would be difficult to determine the effectiveness of the removal from the root surfaces. The writer is of the opinion that the removal is effective enough to influence the composition of the plant if carbon dioxide production is an important factor in the feeding power of plants. Cotton and cowpeas have a high feeding power for calcium. If this is due to the carbon dioxide given off by the plant roots it seems probable that the plants in the aspirated cul-

tures of series 2 would contain a smaller percentage of calcium than those in the non-aspirated cultures of series 1.

TABLE 6

The yield and percentage (dry weight) composition of plants grown in soil cultures with and without the removal of carbon dioxide by continuous aspiration

TREATMENT	SORGHUM	COTTON	BUCK-WHEAT	COWPEAS	SOYBEANS	COWPEAS*	SOYBEANS*
Dry weight of tops							
	gm.	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*
CO_2 not removed	28.45	20.20	12.20	40.40	27.60	25.50†	22.75
CO_2 removed	23.15	20.90	12.50	37.55	28.70	33.65	19.15
Difference	−5.30	0.70	0.30	−2.85	1.10	8.15	−3.60
Ash Content							
	per cent	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*
CO_2 not removed	3.85	9.14	8.76	6.01	6.43	6.45	6.47
CO_2 removed	3.98	7.96	9.48	5.49	5.51	6.19	6.71
Difference	0.13	−1.18	0.72	−0.52	−0.92	−0.26	0.24
Calcium Content							
CO_2 not removed	0.53	2.00	1.00	1.24	1.40	1.34	1.31
CO_2 removed	0.57	1.81	1.22	1.16	1.16	1.49	1.43
Difference	0.04	−0.19	0.22	−0.08	−0.24	0.15	0.12
Magnesium Content							
CO_2 not removed	0.36	0.49	0.79	0.39	0.45	0.43	0.39
CO_2 removed	0.36	0.46	0.83	0.37	0.39	0.40	0.45
Difference	0.00	−0.03	0.04	−0.02	−0.06	−0.03	0.06
Potassium Content							
CO_2 not removed	0.88	1.22	2.33	0.90	1.03	0.92	1.12
CO_2 removed	0.93	1.13	2.29	0.83	0.97	0.82	1.19
Difference	0.05	−0.09	−0.04	−0.07	−0.06	−0.10	0.07
Phosphorus Content							
CO_2 not removed	0.12	0.21	0.12	0.12	0.16	0.13	0.16
CO_2 removed	0.13	0.20	0.13	0.10	0.15	0.12	0.18
Difference	0.01	−0.01	0.01	−0.02	−0.01	−0.01	0.02
Nitrogen Content							
CO_2 not removed	1.46	2.20	2.36	2.39	2.19	2.37	2.47
CO_2 removed	1.65	2.75	2.37	2.13	1.69	2.15	2.28
Difference	0.19	0.55	0.01	−0.26	−0.50	−0.22	−0.19

* Did not receive $NaNO_3$.

† Poor duplication in this culture, 19.8 and 31.2 gms.

Table 6 shows the effect of aspiration on the yield and percentage composition of the different plants. Taken as a whole the results show that aspiration

had very little influence on either the yield or the composition of the crop. There is no evidence that aspiration had a tendency to make all plants have the same composition as would be the case if aspiration removed carbon dioxide and carbon dioxide was the determining factor in the feeding power of plants. The differences in composition are small and probably are not due to the influence of aspiration. In most cases the differences do not merit serious consideration. However, the results given in the table will be discussed to show certain differences that were obtained.

With four of the seven crops the yield in the aspirated cultures was less than in the non-aspirated cultures. With three of the seven crops the plants from the non-aspirated cultures contained a higher percentage of ash, phosphorus and nitrogen than did the plants from the aspirated cultures. This was the case in two instances with magnesium and potassium and in four instances with calcium. In most cases the differences were small and the results would be considered satisfactory duplicates. For example, the maximum difference found in the percentage of magnesium, phosphorus and potassium was only 0.10 per cent. It is evident that aspiration had almost no influence on the composition of the plants.

Considering the effect upon the composition of individual crops it will be seen that with sorghum the percentage of all constituents was greater in the aspirated cultures than in the non-aspirated cultures. With one exception in each case, this was true of all constituents in buckwheat and in the soybeans which did not receive nitrate. The opposite effect is found in the other cultures. Cotton, both cowpea cultures, and the soybean receiving nitrate had a lower percentage of the different constituents in the aspirated cultures. The differences are small in most instances but they are consistent. It seems impossible to attribute the results to the removal of carbon dioxide. Sorghum and cotton produced similar amounts of carbon dioxide but aspiration apparently increased the percentage of all constituents in one and decreased the percentage in another. Opposite results were also secured with fertilized and unfertilized soybeans. These apparently conflicting results lead to one of two conclusions. Either the excretion of carbon dioxide by plant roots is an unimportant factor in the feeding power of plants, or aspiration is not an effective method of reducing the influence of carbon dioxide production on the feeding power of plants. The author considers the first conclusion correct, especially since the preceding experiments on the relation of carbon dioxide production to the feeding power lead to the same conclusions.

EXPERIMENT 3

In the preceding experiments the excretion of carbon dioxide was studied by observing the percentage in the soil air. The purpose of the third experiment was to determine the total amount of carbon dioxide given off by different plants during the growing period and then to determine the total amount of the various elements absorbed by the plants. By this method

it is possible to determine whether the ratio between the amount of carbon dioxide excreted from the roots and the amount of any element absorbed by the plant is the same or different for different plants.

Cowpeas, buckwheat, sorghum and soybeans were grown in 1-gallon glazed earthenware jars. Seven days after planting, as soon as there were good seedlings, the cultures were sealed with an air tight wax seal. Two days later, after it was evident that none of the plants were injured in applying the wax, the plants were thinned. Four cowpea, soybean and sorghum plants, and eight buckwheat plants were grown in a culture. Cultures were in duplicate

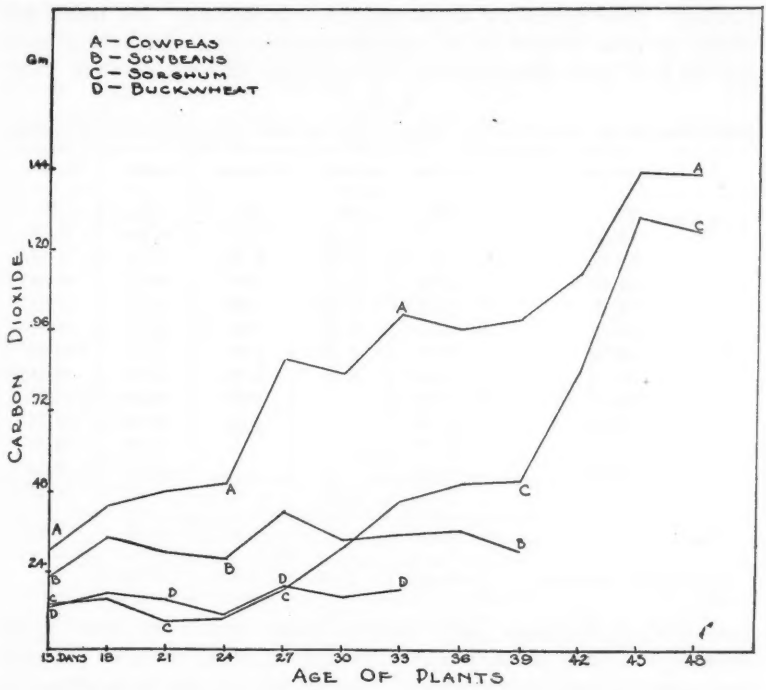


FIG. 2. GRAMS OF CARBON DIOXIDE GIVEN OFF BY THE ROOTS OF DIFFERENT PLANTS DURING SUCCESSIVE 3-DAY PERIODS

and two cultures were carried without a crop. Carbon dioxide determinations were made daily, beginning fourteen days after planting. These determinations were made by aspirating and absorbing the carbon dioxide. The incoming air was freed of carbon dioxide by drawing it through a soda-lime tube. It then passed through a U-tube containing a small amount of water. The cultures were watered through this U-tube, and it served as an indicator as to whether or not the wax seal was perfectly air tight. If bubbling in the U-tube and in the absorption tower was not at the same rate, it indicated a leak in the wax seal. Very little difficulty was experienced in this respect. After passing through the U-tube, the incoming air entered the culture through an inverted two-inch funnel. The large end of the funnel was about two inches below the wax seal. After passing through the soil mass, the air was drawn out at the bottom of the culture and passed through a Truog carbon dioxide absorption

apparatus, containing a measured quantity of 0.4 *N* $Ba(OH)_2$. Aspiration was continuous during most of the day, but was stopped during the night. The carbon dioxide absorption apparatus was disconnected and the excess $Ba(OH)_2$ titrated every day.

The results for carbon dioxide production are shown in table 7. The figures are given for successive three day periods rather than the results of the daily determinations.

The carbon dioxide production of the different plants is obtained by subtracting the results for the no-crop cultures from the results for the other cultures. These figures are shown graphically in figure 2. The results are similar to those secured in the preceding experiments. Buckwheat roots give off very little carbon dioxide. Cowpeas give off large amounts. Soybeans and sorghum show greater differences here than in the preceding experiments. During the early part of the growing period soybeans produced more carbon dioxide than sorghum. This was also the case in experiment 2. (See figure 1). After thirty days the sorghum began to produce much larger amounts of carbon dioxide, and at the time of harvesting it was giving off almost as much as the cowpeas. The sorghum was making a very rapid growth at this time. In general the carbon dioxide production was proportional to the rate of growth.

TABLE 7

Total carbon dioxide secured from soil cultures of different crops during successive 3-day periods

AGE OF CROP	COWPEAS	BUCKWHEAT	SOYBEANS	SORGHUM	NO CROP
days	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*
14–16	0.71	0.54	0.63	0.54	0.40
17–19	0.87	0.61	0.78	0.59	0.43
20–22	0.99	0.66	0.81	0.60	0.51
23–25	1.12	0.73	0.90	0.72	0.62
26–28	1.41	0.75	0.96	0.74	0.54
29–31	1.28	0.61	0.78	0.76	0.45
32–34	1.44	0.62	0.79	0.88	0.43
35–37	1.32	....	0.72	0.86	0.36
38–40	1.34	....	0.64	0.86	0.35
41–43	1.52	....	....	1.22	0.39
44–46	1.84	....	....	1.70	0.40
47–49	1.84	....	....	1.67	0.41
Total.....	15.68	4.51	7.00	11.13	5.28
Increase over no crop.....	10.40	1.12	2.91	5.85	

The yield and composition of the different crops are given in table 8. The results are similar to those secured in the preceding experiments. Table 9 shows the milligrams of the different constituents absorbed by the plant for each gram of carbon dioxide excreted from the plant roots. If the amount of carbon dioxide produced determines the amount of an element absorbed all plants should give similar results. That is, for each gram of carbon dioxide

given off sorghum, buckwheat and cowpeas would take up the same amount of calcium or magnesium. The results show that this is not the case. Widely different results were secured for the different plants. For each gram of carbon dioxide given off by the plant roots, buckwheat took up eight times as much calcium as did sorghum, and more than three times as much as did cowpeas. Buckwheat also took up seven times as much magnesium and four times as much phosphorus per gram of carbon dioxide excreted as did cowpeas or sorghum. Similar comparisons may be made between soybeans and sorghum, soybeans and buckwheat, soybeans and cowpeas, and sorghum and cowpeas. In none of these cases is there much evidence that there is any relation between the amount of carbon dioxide produced and the amount of any element absorbed. Thus this experiment furnishes additional evidence that there is no relation between the carbon dioxide production of a crop and its feeding power.

TABLE 8

The yield and percentage (dry weight) composition of different crops grown in sealed soil cultures

CROP	AGE AT HARVEST	WEIGHT OF TOPS	ASH	Ca	Mg	P	N
	days	*gm.*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*
Cowpeas	49	11.37	5.16	1.16	0.39	0.10	2.19
Buckwheat	34	3.83	9.70	1.22	0.83	0.14	2.52
Soybeans	40	4.40	6.28	1.40	0.47	0.16	3.41
Sorghum	49	5.86	4.20	0.50	0.42	0.11	1.70

TABLE 9

Amount of the different elements absorbed by different crops per gram of carbon dioxide given off by the plant roots

CROP	MILLIGRAMS ABSORBED PER GRAM OF CO_2 GIVEN OFF BY THE ROOTS				
	Ash	Calcium	Magnesium	Phosphorus	Nitrogen
Cowpeas	56.4	12.7	4.28	1.06	24.0
Buckwheat	331.1	41.5	28.16	4.81	86.0
Soybeans	94.9	21.2	7.07	2.44	51.5
Sorghum	42.1	5.0	4.21	1.09	17.0

THE COMPOSITION OF DIFFERENT CROPS GROWN IN QUARTZ SAND CULTURES

In soil cultures the excretion of carbon dioxide has been considered a factor in the feeding power of plants because it is well known that water containing carbon dioxide has a much greater solvent effect on many soil minerals than water free of carbon dioxide. If, as in quartz cultures, the essential elements are supplied in solution the excretion of carbon dioxide should not be a factor in the feeding power of plants. Therefore, if different plants are grown in sand cultures and receive the same nutrient solution they would have the

same composition unless other factors than carbon dioxide production influenced the amount of the different elements absorbed. If the differences found in the composition of the crops grown in nutrient solution are similar to the differences found in the same crops grown in soil cultures it would indicate that the same factors were determining the feeding power in both instances and that carbon dioxide production was not the determining factor in either case.

The composition of different crops grown in sand cultures has been determined by several investigators. Bauer (2, p. 35) determined the percentage of calcium and phosphorus in nine different crops grown in sand cultures with the calcium and phosphorus supplied in soluble and insoluble forms, acid phosphate and rock phosphate. He found that when calcium and phosphorus were furnished as acid phosphate, there were large differences in the calcium and phosphorus content of the different plants. Four leguminous

TABLE 10

Composition of nutrient solution

Ca	NO_3	Mg	SO_4	K	PO_4	Na	Cl	TOTAL
p.p.m.	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*	*p.p.m.*
31	186	51	200	203	175	34	119	996

TABLE 11

The yield and percentage (dry weight) composition of different crops grown in sand cultures

CROP	WEIGHT OF DRY TOPS	ASH	Ca	Mg	K	P	N
	gm.	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*
Velvet beans.....	15.55	10.2	0.61	0.57	3.49	0.53	2.09
Cowpeas.....	17.53	15.2	0.66	0.85	4.80	0.53	1.45
Sorghum.....	23.67	8.8	0.21	0.41	3.63	0.46	0.95

plants had an average calcium content of 1.23 per cent. All of them contained over one per cent calcium. Corn, timothy and redtop had calcium contents of 0.57 per cent, 0.36 per cent and 0.63 per cent, respectively. Very similar differences were found in the calcium content of these plants when rock phosphate was the source of calcium and phosphorus. These differences in the calcium content of the plants are very similar to the differences found when the plants were grown in soil (8).

Bryan (3, 4) grew oats, wheat, alfalfa, red clover and alsike clover in Cone's nutrient solution at different reactions and determined the calcium content of the plants. The same nutrient solution was used for all cultures except that the legumes did not receive nitrate while the non-legumes received nitrate as KNO_3. For the legumes an equal weight of KCl was substituted for the KNO_3, and the plants were inoculated. At pH 7 both the oats and wheat had a calcium content of 0.37 per cent. At the same reaction, alfalfa,

alsike clover and red clover had a calcium content of 0.88 per cent, 0.81 per cent and 0.76 per cent, respectively.

Newton (7) grew barley and peas in a nutrient solution and found they had practically the same composition. Similar results were secured with barley and vetch, but beans were found to have a much higher calcium content than barley when grown in the same nutrient solution.

In order to obtain additional data on the composition of different plants grown in nutrient solutions, the writer grew velvet beans, cowpeas, and sorghum in two-gallon sand cultures. Table 10 shows the composition of the nutrient solution used in these cultures. The nutrient solution was renewed twice a week. The five plants in each culture were harvested thirty-six days after planting. Table 11 shows the dry weight and composition of the different plants.

The composition of the legumes and the sorghum differs widely. Sorghum has a lower ash content than either velvet beans or cowpeas. Its calcium content is only one-third as great as that of the legumes. The latter have a higher magnesium, phosphorus and nitrogen content. The differences are of the same order as found when these plants were grown in soil cultures, table 2. Therefore, it may be concluded that factors, other than the excretion of carbon dioxide from the roots, determine the feeding power of plants.

SUMMARY

Four experiments are reported in which a study was made of the relation between the carbon dioxide production of plant roots and the feeding power of the plant. In experiments 1 and 2 carbon dioxide production was studied by determining the influence of the crop on the carbon dioxide content of the soil air at intervals during the growing period. The feeding power of the plants was studied by determining the composition of the plants and also by considering the total amount of the different elements absorbed.

In the second experiment a study was made of the effect of continuous aspiration of the cultures on the feeding power of the plants as indicated by their composition. Aspiration was continuous during the growing period and was at the rate of about twenty-five liters per hour. In this manner the carbon dioxide content of the air was reduced to 0.20 per cent or less.

The total amount of carbon dioxide excreted from the plant roots was determined in the third experiment. After determining the amount of absorption, the amount of the different elements absorbed per gram of carbon dioxide excreted was calculated for sorghum, cowpeas, buckwheat and soybeans.

In the last experiment absorption from a nutrient solution was determined.

A summary of the results obtained in these experiments follows:

1. More carbon dioxide is excreted from the roots of cowpeas than from the roots of any other plant used in the experiments.

2. Buckwheat roots give off very little carbon dioxide.

3. Sorghum, soybeans and cotton are very similar in carbon dioxide production. They produce much more carbon dioxide than buckwheat.

4. Buckwheat has the greatest feeding power of any of the plants used in the experiments. Cotton ranks second in feeding power and sorghum has the lowest feeding power of all the plants used.

5. No relation was found between carbon dioxide production and the feeding power of the plants for calcium, magnesium, phosphorus or potassium in a rather poor sandy soil.

6. The removal of carbon dioxide by continuous, rapid aspiration did not influence the composition of the plants.

7. Different plants absorb widely different amounts of calcium, magnesium and phosphorus per gram of carbon dioxide excreted from the plant roots. For each gram of carbon dioxide excreted by the roots, buckwheat absorbed 41.5 mgm. of calcium; sorghum, cowpeas and soybeans absorbed 5.0, 12.7, and 21.2 mgm., respectively.

8. Cowpeas, velvet beans and sorghum grown in sand cultures absorbed different amounts of calcium, magnesium and nitrogen. The legumes contained much higher percentages of these elements than did the sorghum.

REFERENCES

(1) Aberson, J. H. 1910 Ein Beitrag zur Kenntnis der Natur der Wurzelausscheidungen. *In* Jahrb. Wiss Bot. (Pringsheim) v. 47, p. 41–56 (original not seen).

(2) Bauer, F. C. 1921 The relation of organic matter and the feeding power of plants to the utilization of rock phosphate. *In* Soil Sci., v. 12, no. 1, p. 21–41.

(3) Bryan, O. C. 1923 The effect of different reactions on the growth and calcium content of oats and wheat. *In* Soil Sci., v. 15, no. 5, p. 375–382.

(4) Bryan, O. C. 1923 Effect of reaction on growth, nodule formation and calcium content of alfalfa, alsike clover and red clover. *In* Soil Sci., v. 15, no. 1, p. 23–35.

(5) Davis, A. R., Hoagland, D. R., and Lipman, C. B. 1923 The feeding power of plants. *In* Science, n.s., v. 57, p. 299–301.

(6) Gile, P. L., and Ageton, C. N. 1914 The effect of strongly calcareous soils on the growth and ash composition of certain plants. Porto Rico Agr. Exp. Sta. Bul. 16.

(7) Newton, J. D. 1923 A comparison of the absorption of inorganic elements, and of the buffer systems of legumes and non-legumes, and its bearing upon existing theories. *In* Soil Sci., v. 15, no. 3, p. 181–204.

(8) Parker, F. W., and Truog, E. 1920 The relation between the calcium and nitrogen content of plants and the function of calcium. *In* Soil Sci., v. 10, p. 49–56.

(9) Pfeiffer, Th., and Blanck, E. 1912 Die Säureausscheidung der Wurzeln und die Löslichkeit der Bodennährstoffe in Kohlensaurehaltigem Wasser. *In* Landw. Vers. Sta., v. 77, p. 217–268 (original not seen).

(10) Truog, E. 1915 Methods for the determination of carbon dioxide and a new form of absorption tower adapted to the titrimetric method. *In* Jour. Indus. Engin. Chem., v. 7, p. 1045.

(11) Truog, E. 1916 The utilization of phosphates by agricultural plants, including a new theory regarding the feeding power of plants. Wis. Agr. Exp. Sta. Res. Bul. 41.

(12) TRUOG, E. 1922. The feeding power of plants. *In* Science, n. s., v. 56, p. 294–298.
(13) TURPIN, H. W. 1920 The carbon dioxide of the soil air. Cornell Agr. Exp. Sta. Mem. 32.
(14) SHEDD, O. M. 1922 Effect of certain calcium compounds and other substances on the yield and calcium content of some crops. *In* Soil Sci., v. 14, p. 233–246.
(15) STOKLASA, J., AND ERNEST, A. 1909 Beiträge zur Lösung der Frange der Chemishen Natur des Wurzelsekretes. *In* Jahr. Wiss. Bot. (Pringsheim) v. 46, p. 55–102 (original not seen).
(16) WILKINS, LOUIS, K. 1917 The high calcium content of some cucurbit vines. N. J. Agr. Exp. Sta. Bul. 310.

THE LOSS OF CALCIUM CARBONATE IN DRAINAGE WATER AS AFFECTED BY DIFFERENT CHEMICAL FERTILIZERS[1]

F. W. MORSE

Massachusetts Agricultural Experiment Station

Received for publication January 8, 1924

During the study of problems relating to the use of sulfate of ammonia at this station, numerous data have been accumulated by the analysis of the drainage-waters from the plots used in the fertilizer experiments. When these results were collated and compared, it was noted that the differences in composition of the waters from the various plots were consistent throughout the several years and seasons in which the samples had been collected and analyzed.

The field containing the fertilizer plots has been frequently described (2, 3, 4) under the designation "Field A." It is nearly level, with but a slight slope toward the east and is divided into plots of 0.1 acre each, which are separated from one another by strips of land 5 feet wide. Each plot is 8 rods long and 2 rods wide. Lengthwise of the middle of each plot runs a drain of 2-inch tile at the depth of 3 feet, and its outlet is at the eastern end in a well 2 feet in diameter and 4 feet in depth. A main drain of 6-inch tile runs along the eastern border of the field at a depth of 4 feet and drains the wells.

The surface soil of the field is quite uniform and has been classified as Merrimac sandy loam (10). The mixture of chemicals for each plot has always been applied uniformly over its surface and none has been applied to the strips between the plots. It has been assumed that no cross percolation from plot to plot takes place, as the growing crops show a sharp boundary between the fertilized and unfertilized areas.

During the periods in which the drainage-waters were analyzed, the applications of lime were made upon all the plots, but upon only one-half of each area. The water from each drain however must represent the whole surface of the plot, therefore the concentration of lime in the drainage-waters is necessarily less than it would have been if the application of lime had been made to the entire plot. Hydrated lime was applied in 1909 at the rate of 2.5 tons per acre and in 1913 at the rate of 2 tons; in 1919, ground limestone was applied at the rate of 1 ton per acre. In the earlier history of the field, hydrated lime had been applied to the whole field in 1898 and in 1905, at the rate of 1 ton per acre each time.

Every plot has received dissolved phosphate which supplied 80 pounds of available phosphoric acid per acre annually. Potash salts were applied to supply 125 pounds of actual potash per acre, but some of the plots received muriate of potash every year, while others received sulfate of potash and magnesia. Three plots received no nitrogenous fertilizer throughout the period, but the rest had applied to them 45 pounds of nitrogen per acre yearly, two receiving nitrate of soda, three sulfate of ammonia, and two dried blood, as the sources of the element.

---

[1] Published by permission of the Director of the Massachusetts Agricultural Experiment Station.

The distribution of the potash salts and the nitrogenous fertilizers among the plots was as follows:

Plot 1	Nitrate of soda	Muriate of potash
Plot 2	Nitrate of soda	Sulfate of potash and magnesia
Plot 3	Dried blood	Muriate of potash
Plot 4	No nitrogen	Sulfate of potash and magnesia
Plot 5	Sulfate of ammonia	Sulfate of potash and magnesia
Plot 6	Sulfate of ammonia	Muriate of potash
Plot 7	No nitrogen	Muriate of potash
Plot 8	Sulfate of ammonia	Muriate of potash
Plot 9	No nitrogen	Muriate of potash
Plot 10	Dried blood	Sulfate of potash and magnesia

The drains have always discharged most freely in the spring; but have ceased to flow by the time the surface is dry enough to be worked satisfactorily. Seldom has any water run from the tiles during the growing season. Late in the fall, however, there has been some flow shortly before the ground has frozen. The drainage-waters have consequently represented in general the soil conditions after the crops have absorbed all the soluble fertilizers which they required. The few samples secured in the summer season are, however, similar in their relation to their respective plots, to the spring and fall samples.

Most of the data here presented were obtained by Mr. R. W. Ruprecht during the years 1912, 1913 and 1914, in connection with a study of the effects of ammonium sulfate upon the soil. Since then, the writer obtained the summer samples during some abnormally wet seasons, and a few spring samples to check previous observations.

The spring of 1912 followed an unusually cold March and frost was not out of the ground until the last week of that month. In 1913 it was unusually early following a mild winter. The samples obtained in 1914 did not represent the total flow but were secured as a check on the previous seasons. The samples of May 22, 1919, were taken because a fresh application of lime was to be made as soon as the soil could be worked, and these samples would represent the extreme exhaustion of calcium during the period.

The two fall seasons followed somewhat dry summers, although rainfall had been well distributed and crops had not suffered. In 1912, the drains began to discharge after a rainy period of about two weeks, but in 1913 the flow began after an unusually heavy rainfall on the previous day. The three sets of fall samples were each obtained relatively early in the flow from the tiles.

The summer of 1915 was characterized by heavy drenching showers early in July with about six inches of rainfall recorded in six days. The first few days of August were similar. In all probability there was a flow from the drains in July, but other work engrossed our attention. The downpour in August suggested the collection of a summer series of samples, which was made and analyzed. In 1921, moderate rains followed one another closely for a considerable period until at length water appeared at the tile outlets and samples were obtained.

The concentration of salts in the drainage-waters probably varied with the length of time after the flow began from the tile, and the samples may have only approximately represented the composition of the total drainage from a plot. However, it is obviously impracticable to measure and sample accurately by hand, a flow which continues for hours and varies from a mere trickle to a stream as large as the tile will permit.

TABLE 1

Calcium (Ca) in drainage water

DATE	SOIL WITH SODIUM NITRATE	SOIL WITH NO NITROGEN	SOIL WITH AMMONIUM SULFATE	
	Plot 1	Plot 7	Plot 6	Plot 8
	p.p.m.	*p.p.m.*	*p.p.m.*	*p.p.m.*
Spring				
1912. April 1	18.0	15.0		31.0
	15.0	11.5		26.5
April 5	12.0	12.5	27.0	26.5
April 23	16.5	18.0		33.5
May 17	18.5	27.0	38.0	42.0
1913. March 5	24.8	35.2		
March 9	13.6	28.8	38.9	31.1
March 14	28.1	28.3	38.1	50.8
March 21	35.4	42.1	54.5	71.9
March 28	29.4	41.5	46.7	63.3
April 5	30.0	46.5	61.4	69.6
May 29	27.2	42.2	51.6	63.3
1914. April 9	29.4	41.8	40.8	58.9
May 6		40.8	49.4	
1919. May 22	32.8	46.4		66.4
Fall				
1912. November 15	27.4	46.3	84.1	81.3
December 6	32.5	55.0	83.0	68.0
1913. December 8	28.4	48.0	59.3	69.1
Summer				
1915. August 5	36.0	75.6		111.6
1921. July 21	16.4	27.8		44.2
Average	24.8	36.5	54.2	

The samples were secured by means of a tin vessel attached to a long wooden handle, by which the vessel could be held under the outlet of the small tile within the well. In the earlier work, the samples were obtained only when the water was running freely from the tile; but later, by producing a sharp edge on the tin and bending it to conform to the curved wall of the well, it was possible to collect the water even when the flow was so scanty that the water ran back on the under side of the tile and spread in a thin film down the wall. The water was transferred from the tin vessel to a glass-stoppered bottle, which had been previously rinsed with some of the sample, and in which the water was kept until analyzed.

Calcium was determined by precipitating it as calcium oxalate, using enough water to yield a satisfactory precipitate on concentrating the solution upon the water-bath. The

earlier determinations were completed by titrating the oxalate with a standard solution of potassium permanganate; but the later results were obtained by igniting the precipitates and weighing the calcium oxide.

Throughout the series, there has persisted the difference in the concentration of calcium in the waters from the three types of fertilizer. The average composition of the different waters shows that the addition of ammonium sulfate to the common mixture of phosphate and potash increased the concentration of calcium 50 per cent, while sodium nitrate decreased it in about the same proportion.

Since there was no way of measuring the amount of drainage-water from each plot, the annual loss of calcium carbonate from the soil cannot be satisfactorily estimated. The concentration of calcium in the waters would undoubtedly have been greater if the application of lime had been made to the whole of each plot instead of to one-half. On the other hand a small part of the calcium must have come from the calcium sulfate which accompanied the phosphate. No other drainage-water analyses that are comparable have come to the writer's attention. MacIntire (7) and Lyon and Bizzell (6) have reported losses of calcium carbonate in lysimeters; but neither nitrate of soda nor sulfate of ammonia were among their fertilizers.

Results with the drainage waters have been corroborated by another distinctly different set of analyses, namely the determination of the residual $CaCO_3$ in the surface soil of each plot. Samples were taken in November, 1920, from the sections that had been most heavily limed. The last application was made in May, 1919, therefore it was about eighteen months afterward when the samples were secured. Since all the lime was applied broadcast to the surface and worked into the soil with a harrow it was considered that borings taken to the depth of six inches would correctly represent the amount of soil that originally contained the $CaCO_3$.

The residual $CaCO_3$ was estimated from the determination of the combined carbon dioxide in the soils, all the analyses of which were performed by Mr. C. P. Jones, who used the method of MacIntire and Willis (8).

It will be noted that the residual $CaCO_3$ in the three soils stands in the reverse order to the calcium in the drainage waters, with the residue in the nitrate soil about twice that in the ammonia soil. It is not considered reliable to estimate the annual losses by calculating the difference between the total $CaCO_3$ applied to the surface and the residue found, because there is no certainty that the supply was not exhausted in the interval between 1913 and 1919, especially on the ammonia plot where crop growth indicated it. The residues found may be those from the last application in 1919. The surface soil might lose $CaCO_3$ faster than would be shown by the drainage-water, because the lower depths would hold some by absorption. This absorption would vary with the fertilizer treatment, for all our work with soil extracts has shown much quicker percolation through the soils from the ammonia plots than through those from the nitrate plots.

At Rothamstead (5) the annual losses of $CaCO_3$ have been computed by comparing the analyses of the soil made forty years apart. In this case the quantity of $CaCO_3$ was so large that there was no question of an exhaustion in the interval and no applications were made during the period. The annual losses were calculated to be 1100 pounds $CaCO_3$ from the ammonia plots and 565 pounds from the nitrate plot.

The marked effect of sulfate of ammonia is due to the hydrolysis of the salt in the soil water, with the formation of H_2SO_4 and NH_4OH. The former will change $CaCO_3$ to $CaSO_4$ while the latter is ultimately nitrified and changes $CaCO_3$ to $Ca(NO_3)_2$.

The lessened amount of calcium in the drainage-water from the nitrate plot may be explained in the following manner. The fertilizers when applied to the soil are in fine, solid particles, fairly well mixed. The soil at the time

TABLE 2

Calcium carbonate in soils, November, 1920

	$CaCO_3$ IN SOIL	$CaCO_3$ PER ACRE SIX INCHES
	p.p.m.	*lbs.*
Plot 1, with $NaNO_3$	1057	1585
Plot 7, with no N	789	1183
Plot 8, with $(NH_4)_2SO_4$	518	777

is not very moist and is usually becoming drier as the days pass. The actual moisture with which the fertilizer particles come in contact may not be more than sufficient to form a saturated solution at that point. Further drying of the soil may cause a recrystallization in which will first form crystals of KNO_3 as the least soluble component of the reaction

$$NaNO_3 + KCl \rightleftharpoons KNO_3 + NaCl.$$

The NaCl will dissolve more quickly and the $CaCO_3$ is less soluble in its presence than with KCl (1). The KNO_3 will be taken up by the growing crop soon after germination is completed, as the salt slowly dissolves.

There is a slight possibility that when NaCl reacts with $CaCO_3$ to form Na_2CO_3 there may be formed a double compound like the mineral gaylussite, which is very insoluble; but little is known about such double carbonates.

SUMMARY

Drainage waters from soils dressed with three typical combinations of chemical fertilizers have been analyzed for calcium at different seasons of the year.

The amount of calcium carbonate removed from the soil where sulfate of ammonia was used was more than twice as large as that where nitrate of soda was the nitrogenous fertilizer.

Nitrate of soda added to an application of dissolved phosphate and muriate of potash protected the calcium carbonate somewhat.

The results with drainage waters were corroborated by the determination of the residual calcium carbonate in the soils of the plots.

REFERENCES

(1) CAMERON, F. K., AND BELL, J. M. 1907 The action of water and aqueous solutions upon soil carbonates. U. S. Dept. Agr. Bur. of Soils Bul. 49.

(2) GOESSMANN, C. A. 1890 Field experiments to ascertain the effect of different combinations of nitrogen, nitrate of soda, sulphate of ammonia and organic-nitrogen-containing compounds, blood, under otherwise corresponding circumstances, on oats. Field A. *In* Mass. Agr. Exp. Sta. 8th Ann. Rpt., p. 149–157.

(3) GOESSMANN, C. A. 1891 Field experiments to ascertain the effect of different combinations of nitrogen—i.e., sodium nitrate, Chile saltpetre, ammonium sulphate, and nitrogen-containing organic matter, under otherwise corresponding circumstances on rye. Field A. *In* Mass. Agr. Exp. Sta. 9th Ann. Rpt., p. 172–179.

(4) GOESSMANN, C. A. 1892 Field experiments carried on for the purpose of ascertaining the effect of the exclusion of every form of nitrogen-containing manurial matter from the fertilizer applied for the production of a leguminous crop (clover-like plants) on the yield, as compared with the results obtained when a liberal amount of various nitrogen-containing manurial substances is applied under otherwise corresponding circumstances for the same purpose. Field A. Soja bean. *In* Mass. Agr. Exp. Sta. 10th Ann. Rpt., p. 170–177.

(5) HALL, A. D. 1919 The Book of the Rothamstead Experiments, 2nd ed. J. Murray, London.

(6) LYON, T. L., AND BIZZELL, J. A. 1918 Lysimeter experiments. Cornell Univ. Agr. Exp. Sta. Mem. 12.

(7) MACINTIRE, W. H. 1919 Carbonation of burnt lime in soils. *In* Soil Sci., v. 7, p. 325–453.

(8) MACINTIRE, W. H., AND WILLIS, L. G. 1913 Soil carbonates, a new method of determination. Tenn. Agr. Exp. Sta. Bul. 100.

(9) MORSE, F. W. 1921 Thirty years' experience with sulfate of ammonia. Mass. Agr. Exp. Sta. Bul. 204.

(10) WHITNEY, M. 1909 Soils of the United States. U. S. Dept. Agr. Bur. of Soils Bul. 55.

ADSORPTION AND ABSORPTION OF BASES BY SOILS

CARLETON P. JONES[1]

Massachusetts Agricultural Experiment Station

Received for publication November 21, 1923

The terms adsorption and absorption are used to express the results observed due to contact between the surfaces of different substances or bodies, all of which are endowed with potential energy, either physical or chemical or both, the former being confined to surface area alone while the latter is distributed throughout the entire mass.

Any attractive force due to physical energy alone is a surface area phenomenon and is termed adsorption. Absorption is primarily the result of active chemical forces, but as all substances or bodies are endowed also with physical energy and, as physical forces are exerted at the surfaces of the attracting bodies, the physical phenomenon must precede the chemical and therefore adsorption must take place before absorption. In line of this reasoning absorption may be considered as a physical-chemical phenomenon.

All soils no matter of what origin exhibit to a greater or less degree the phenomena of adsorption and absorption, the substances attracted, of organic or inorganic composition, being derived either directly from the air, the soil atmosphere or from aqueous solutions of substances contained in the soil.

SUBSTANCES IN SOIL WHICH CAUSE ADSORPTION AND ABSORPTION

The existence in the soil of various substances which exhibit the power of attraction and decomposition of certain compounds in solution can be easily demonstrated by the passage of weak solutions of various bases or salts through a given volume of soil. An examination of the extract clearly shows that definite amounts of substances have been removed from the solution used and furthermore the percentage of total abstraction is dependent upon the temperature and concentration of the solutions.

In the treatment of soil with salt solutions it is generally found that double decomposition results to a greater or less degree; the basic ions of the salt solution applied being retained by the soil because of base substitution, while the acid ions, neutralized by the replaced base, are removed by percolation.

[1] Published with the permission of the Director of the Massachusetts Agricultural Experiment Station.

The writer wishes to express his appreciation to F. W. Morse for helpful suggestions in the presentation of the subject matter.

The retention of basic ions illustrates positive absorption, whereas the holding of acid ions, which is possible in some cases, would denote negative absorption.

The soil constituents causing adsorption may be said to include every individual substance of a solid or a partially solid nature contained in the soil, for it has been previously stated that adsorption is a physical phenomenon and is purely related to surfaces alone. The fact that adsorption is wholly concerned with surfaces would be indicative that the degree of adsorption is controlled by the amount of surface area, or in other words, the finer the division of particles concerned the greater the adsorption. From this, one would naturally expect that gelatinous and colloidal substances would be capable of exhibiting a larger degree of adsorption than material in a more coarsely dispersed phase. The question, however, can be raised, in dealing with colloid materials, just where does adsorption end and absorption begin?

Both the degree of adsorption and of chemical reaction are controlled by the fineness of division of the particles concerned. Therefore, it is quite evident that certain observed phenomena may be misinterpreted in terms of adsorption when in reality the effect observed may be due almost entirely to absorption. This is particularly true in those cases in which decomposition takes place, interchange of bases, or when the abstraction of substance is a very appreciable quantity.

It is believed that any substance in the colloid state is as finely divided as it can possibly be and still be almost wholly without the soluble phase. It is also believed that transformation of practically insoluble substances from a dispersoid to the colloid state generally results in a partial solution of the colloid. The fact that a colloid is soluble to a slight degree would favor chemical reactions taking place, the rate and degree of magnitude depending not only upon the solubility product of the colloid in question but also upon the fact of whether or not the product of the reaction is removed from the medium through which the reaction was enabled to take place.

The various soil constituents causing adsorption and absorption are usually termed dispersoids, gels or colloids. It is stated that the weathering of crystallized minerals nearly always yields gels or a mixture of gels (2). Ostwald (1) and many others claim that the products resulting from fermentation and decomposition of organic matter in the soil result in the formation and development of humic compounds which are of a colloidal nature. Therefore there results in the soil the presence of two distinct classes of colloidal substances whose origin and composition is either inorganic or organic. Of the typical inorganic colloids or those gels which occur in the soil three kinds deserve particular mention, namely, silicic acid and the silicates, aluminum hydroxide and its compounds with silicic acid (of which clay is a representative type) and iron hydroxide. The organic colloids, which are of exceedingly great importance are represented largely by that class of substances, rich in carbon and of unknown chemical composition, which are commonly termed humic compounds. To the class of organic colloids, according to Ostwald,

must be added the microörganisms of various kinds—like the soil bacteria—because of the fact of their being microscopical in size, suspensions of them show coagulative phenomena. To this list must also be added the mucinous substances which are secreted by such soil organisms.

It would not be out of place to include among the living organisms of the soil the various fungi, which are also known to be present, because of their coagulating and adsorptive powers.

SURFACE AREA AND ADSORPTION

That the physical phenomenon, termed adsorption, as exhibited by soils and other material, is most largely controlled by the fineness of division of the particles concerned or by the large surface area resulting from their very small size, is shown by the following tests made with sand and soil under varying conditions.

The sand used was of a pure quartz variety and was previously subjected to a dilute hydrochloric acid digestion, the acid being removed by filtering and washing. It was then dried at about 80°C., ground and passed through 40-, 60-, 150- and 200-mesh sieves. Ten-gram portions of sand representing the particles of each size were transferred to small Erlenmeyer flasks and 100-cc. of a series of solutions containing 10, 20, 30, 40, 50, 60, 70, 80, 90 and 100 cc. of a standard (saturated) solution of calcium hydrate[2] was added to each flask which was then stoppered and allowed to stand, with shaking for 48 hours. At the end of this time the solutions were filtered and the free calcium hydroxide was determined by titration of a 50-cc. aliquot with standard hydrochloric acid.

The soil used is characterized as a silty loam variety and consisted of an air-dried sample taken from the limed end of one of the station plots. The portion employed consisted of the material which passed through a sieve of 200 meshes to an inch. Ten-gram portions were taken for the tests which were carried out as with the sand.

The results given in table 1 clearly indicate an increase in the amount of base absorbed with an increase in concentration of calcium hydrate solution used. The reverse is apparent in respect to the percentage of calcium hydrate adsorbed, for the highest percentage adsorption was obtained by the use of the lowest concentration and the lowest with the highest concentration. It is also noticeable, in the case of the sand, that the larger the surface area the greater the amount of adsorption. This latter phase is very much more marked in the comparison of results obtained by the use of 40-mesh, 200-mesh, and smaller particles. With the soil, as with the sand, the amount and percentage of base adsorbed was found to be dependent upon the concentration of the hydrated solution used.

The adsorptive effect as shown by treating previously ignited sand and soil with different amounts of calcium hydrate solution, and the effect produced by evaporating to dryness on the steam bath, both sand and soil, before and after ignition, with different quantities of the solution, is well illustrated in table 2.

[2] One cubic centimeter of the standard (saturated) calcium hydrate solution used was equivalent to 0.00123 gm. calcium oxide.

The results obtained by the use of sand are attributed to a purely physical action, and any observed adsorption may be considered as a rough measurement of the attracitve force or energy contained in the total surface area represented by the numerous sand particles. The large increase in adsorption as noted by the use of ignited sand is in accord with the above statement, for theoretically at least, with the previous destruction and consequent removal of the thin moisture or water film surrounding each particle of sand grain, contact afterwards with substances in solution should result in an increased extraction and fixation of substances from the solution. This is apparently what has happened in this case for it is inconceivable that any appreciable neutralization of the base occurs as the result of a chemical reaction taking place between the base and a hydrolyzed product of the silica. Any absorption due to chemical reaction must be considered as a negligible quantity.

TABLE 1

Adsorption of CaO from lime-water by sand and soil of different sized particles

LIME WATER IN 100 CC. SOLUTION	CaO ADSORBED FROM 10 GM. SAND OR SOIL									
	Sand between 40- and 60-mesh		Sand between 60- and 80-mesh		Sand between 150- and 200-mesh		Sand finer than 200-mesh		Soil finer than 200-mesh	
cc.	*mgm.*	*per cent*	*mgm.*	*per cent*	*mgm.*	*per cent*	*mgm.*	*per cent*	*mgm.*	*per cent*
10	0.34	2.80	0.47	3.80	0.98	8.00	2.39	19.40	12.24	99.54
20	0.52	2.10	0.42	1.70	1.08	4.40	3.57	14.50	23.94	97.30
30	0.52	1.40	0.64	1.73	0.44	1.20	3.89	10.53	36.51	98.93
40	0.69	1.40	0.77	1.55	1.30	2.65	4.87	9.90	48.36	98.30
50	0.49	0.80	0.37	0.60	1.06	1.72	4.65	7.56	59.66	97.00
60	0.37	0.50	0.37	0.50	1.38	1.87	4.97	6.73	70.08	94.97
70	0.74	0.85	0.37	0.43	1.72	2.00	5.29	6.14	79.73	92.60
80	0.52	0.53	0.47	0.48	1.87	1.90	5.12	5.20	89.52	90.97
90	0.52	0.47	0.49	0.33	1.70	1.53	5.02	4.53	98.06	88.58
100	0.47	0.38	0.64	0.52	1.99	1.62	5.81	4.72	106.40	86.50

In the case of the soil any plausible interpretation must of necessity be vastly different. The amount of base removed from the solution must be the result of the combination of energy derived from both the physical and chemical properties of the soil grains. Just what proportion may be attributed to each cannot be calculated, for as an increase in the intensity of physical attraction is brought about by a previous dehydration of the soil used, the ignition, although possibly destroying a small portion of the material capable of showing adsorption, is far more destructive to those substances contained in the original soil, which are chemically active toward bases in solution, such as organic and inorganic colloids, various acids and acid salts.

The following reasoning is assumed to explain the much greater basic extraction by the soil compared with that obtained by the sand, and that the greater part of the total base removed from solution is the result of absorption rather than adsorption.

The soil which passed through the 200-mesh sieve must without question represent a larger total surface area than the sand which passed through the same sieve, owing to its silty character. Both increase in surface area and ignition result in an increase in adsorption. It was found that ignition, in case of the sand, increased the adsorption of base approximately six or seven times (table 2, test 3 and 4). If the result obtained with the soil (table 2, test 2) was due to adsorption alone, or even largely to adsorption, then the result obtained with ignited soil (table 2, test 3 and 4) should at least be approximately six or seven times as great as the former. But as this is not the case,

TABLE 2

Comparison of absorption of CaO by fine sand and by soil

TEST NO.	TREATMENT	CaO ABSORBED FROM 10 GM. SAND OR SOIL			
		Sand, 200-mesh		Soil, 200-mesh	
		gm.	*per cent*	*gm.*	*per cent*
1	50 cc. H_2O + 50 cc. $Ca(OH)_2$.....	0.00494	8.04	0.05966	97.00
2	100 cc. $Ca(OH)_2$.....	0.00777	6.32	0.10640	86.50
3	Material previously ignited 50 cc. H_2O + 50 cc. $Ca(OH)_2$.....	0.02641	42.94	0.04854	78.92
4	Material previously ignited 100 cc. $Ca(OH)_2$.....	0.04809	39.10	0.10573	85.96
5	50 cc. $Ca(OH)_2$ added, evaporated to dryness, made up to 100 cc. with H_2O.	0.04873	79.24	0.06118	99.48
6	100 cc. $Ca(OH)_2$ added, evaporated to dryness, made up to 100 cc. with H_2O.	0.10652	86.60	0.12152	98.80
7	50 cc. $Ca(OH)_2$ added to ignited material, evaporated to dryness, made up to 100 cc. with H_2O.....	0.06128	99.64	0.05786	94.01
8	100 cc. $Ca(OH)_2$ added to ignited material, evaporated to dryness, made up to 100 cc. with H_2O.....	0.11476	93.30	0.11493	93.44

and as the results are quite similar in both instances, it is evident that absorption played a greater part than adsorption in the soil.

The results derived by evaporating the mixtures of sand or soil with calcium hydrate solution to dryness upon the steam bath are considerably higher than the results obtained in the other treatments, especially in reference to sand. These results may be looked upon as not comparable to those obtained without the aid of evaporation for the following clearly apparent reasons:

1. The influence of heat during the evaporation facilitates an increase in any chemical reaction.

2. Differences in the length of time the mixture of sand or soil and calcium hydroxide is allowed to remain on the steam bath after dehydration has been accomplished would mean variations in the amount of free base found as afterwards determined in the solution.

3. The longer the time for the evaporation and total exposure of the calcium hydroxide to the atmosphere the greater the amount of carbonation of base.

4. Another source of error is due to the fact that carbonation of the calcium hydrate takes place during the process of filtration and to some extent during the time consumed in titrating. The rate of change of hydrate to carbonate depends upon the amount of carbon dioxide in the atmosphere during the process of manipulation, and also, is proportional to the concentration of the solution. Therefore in the employment of calcium hydrate solutions of increasing strengths there would naturally result corresponding increases in carbonate formed, which expressed in terms of the experiment would show progressive increases in basic adsorption.

ABSORPTION EXPERIMENTS

Differentiation between the amount of base adsorbed and absorbed is clearly impossible by the use of lime-water or any other solution of pure base, for the amount of free base left in solution, unacted upon, is the difference between the total amount of base contained in the solution added to the soil, and the amount withdrawn from solution or neutralized, under ordinary conditions, by the combined effects of surface area energy and molecular or ionic energy. If adsorption is a purely physical action and absorption the results of chemical attractions, then there should exist some means of estimating, to some extent at least, the amount of base absorbed by any given soil. By the employment of certain salt solutions and through mass action, it is believed that basic absorption may be estimated with fair accuracy. This belief is based on the fact that accompanying base absorption there results a corresponding degree of salt decomposition, and therefore a measurement of the liberated acid ions in solution will be indicative of the amount of base any given weight of soil will be capable of extracting from solution.

The amount of base that a soil will actually absorb is dependent upon the character and composition of the salt used, for hydrolysis, and the factors influencing the hydrolysis of a salt in aqueous solution, are of primary importance in the calculation of the basic absorptive capacity of any given soil.

Calcium carbonate in the precipitated form was selected as the salt for the following reasons:

1. Carbon dioxide resulting from the decomposition of the carbonate is indicative of chemical reactions or absorption, and is readily measured.
2. This easily decomposable, weakly basic salt is the soil corrective most generally used.
3. Precipitated calcium carbonate is susceptible to the action of very slight concentrations of hydrogen-ions.
4. Carbonate of lime has a low solubility product and the degree of hydrolysis is affected only to a very slight degree by changes in room temperature.

The principle involved in the following method is based on a modified Tacke method which consists in the addition of CO_2-free distilled water to a given weight of a soil or other material and precipitated chalk or other carbonates. Any carbon dioxide resulting from the reaction is removed by the passage of carbon dioxide free air through the solution. The amount of liberated carbon dioxide determined constitutes the measurement of basic absorption.

DESCRIPTION OF METHOD

The apparatus employed is original and so designed as to enable the operator to make four distinct tests at the same time and also facilitates the use of solutions of carbonates (molar) as well as carbonates in the solid state. When the latter are used the carbonate is added to the soil or other material contained in small Erlenmeyer flasks which are then connected to the apparatus. Before adding the water, which furnishes the only medium through which a reaction between the reactive substances and the hydrolyzed products of the carbonate can take place, any free carbon dioxide is removed from the flasks and apparatus by drawing CO_2-free air (by suction) through the apparatus. In the experiments in which solutions of carbonates are employed, the preparation for the tests is somewhat modified. As four separate tests are carried out simultaneously and each equal weight of soil is treated with an equal volume of solution but of different concentrations, it is necessary to supply individual openings to each flask for the admittance of the solutions used. This is accomplished by inserting pieces of glass tubing, provided with short pieces of rubber tubing at the ends, through the rubber corks of the Erlenmeyer flasks containing the material to be tested. These individual openings, and the employment of attached rubber tubing, allow for the addition of the carbonate solutions to the material without change in concentration and moreover without admitting atmospheric carbon dioxide to the flasks. After the addition of the solution to the flask the aperture is made air-tight by plugging with a piece of solid glass tubing or by the use of a pinchcock.

PROCEDURE

Fifty grams of air-dried soil or other material (the weight taken depending upon the bulk) are transferred to small Erlenmeyer flasks. Definite weights of carbonates (alkali or alkaline earth) are added to the material in the flasks, which are then connected to the apparatus. If solutions of carbonates are used the material whose basic absorptive power is to be obtained is transferred to the flasks and attached to the apparatus. Carbon-dioxide-free air is then drawn through for five minutes to replace the air in the flasks and apparatus. Known volumes of standard $Ba(OH)_2$ solution (approximately 0.05 *N* standardized against 0.1 *N* HCl) which has been protected from atmospheric carbon dioxide, are measured from a burette into a series of four small Erlenmeyer flasks which constitutes the train carrying the absorption solution for each separate test. The four series of absorption flasks are connected to the apparatus.

When using solid carbonates, 50 cc. of distilled water are added to each flask by means of the separatory funnel.

When using carbonate solutions, 50 cc. volumes of carbonate solutions, containing definite weights of dissolved carbonates as described above, are added.

After the addition of the water or the carbonate solutions the flasks are shaken as a unit for a period of thirty minutes, during which time air is being constantly drawn through the mixture. The passage of air is continued, with shaking of flasks every now and then, for four hours. The evolved carbon dioxide is swept out of the reaction flasks into the absorption flasks where it is retained as barium carbonate. The excess of standard $Ba(OH)_2$ solution is then determined by titrating with 0.1 *N* HCl, using phenolphthalein, or better, thymolphthalein[3] as indicator.

---

[3] Thymolphthalein is preferred as an indicator in this case because its use makes possible a more definite end-point. Its superiority is especially noticeable in the presence of considerable amounts of $BaCO_3$. The value of this indicator is due to its slightly higher pH value which consequently decreases the sensitiveness to a slight degree toward the hydroxyl-ions resulting from the hydrolysis of the $BaCO_3$ precipitate.

Blank tests are made by using same volume of water and same weight of carbonate. The amount of carbon dioxide, resulting from the absorptive decomposition of the carbonate used, minus the carbon dioxide obtained in the blank tests, in terms of the base of the carbonate used represents the basic absorption of the material tested.

It is plainly evident upon consulting table 3 that absorption is directly based upon the hydrolysis of the salt used. The salts composed of the weaker bases

TABLE 3

Absorption by an unlimed soil of the bases from different carbonates expressed in terms of evolved CO_2

SOLUTION USED		CO_2 FROM 10 GM. SOIL	SOLUTION USED		CO_2 from 10 GM. SOIL
		mgm.			*mgm.*
0.001 *M*	Li_2CO_3	0.4	0.015 *M*	K_2CO_3	6.3
0.01 *M*		3.9	0.03 *M*		7.9
0.02 *M*		5.3*	0.046 *M*		6.3
0.03 *M*		5.7*	0.06 *M*		3.8
0.04 *M*		4.8*	0.12 *M*		1.2*
0.05 *M*		3.2	Saturated solution		0.2*
0.10 *M*		1.6	0.06 *M*	$NaHCO_3$	15.3
0.20 *M*		1.2	0.12 *M*		19.7
0.01 *M*	Na_2CO_3	3.7	0.06 *M*	$KHCO_3$	22.4
0.02 *M*		4.6	0.12 *M*		18.0
0.03 *M*		4.4	0.06 *M*	$MgCO_3$†	5.7
0.04 *M*		4.4*	0.12 *M*		5.2
0.05 *M*		4.3	0.06 *M*	$CaCO_3$†	6.0
0.06 *M*		2.4*	0.12 *M*		6.7
0.10 *M*		1.1	0.06 *M*	$SrCO_3$†	3.1
0.20 *M*		1.0	0.12 *M*		5.1
0.50 *M*		0.7	0.06 *M*	$BaCO_3$†	7.5
Saturated solution		0.3*	0.12 *M*		6.6

* Average of two determinations.

† Very slightly soluble in water but expressed in molar terms for comparison.

(alkaline earth bases) are absorbed to a greater degree than are the salts composed of the stronger alkali bases (lithium, sodium, and potassium). This holds only in the comparison of the neutral salts for it is seen that the base of the acid salts (bicarbonate) of sodium and potassium are absorbed to a greater extent than the bases of the neutral salts. From the standpoint of hydrolytic dissociation the acid salts are hydrolized to a greater degree than neutral salts. It is believed that the bicarbonate of the alkaline earth metals,

such as barium and calcium would show a larger basic absorption than the bicarbonates of the alkali metals. The concentration of the more soluble carbonates influences to a larger degree the base absorption as shown in table 3. The percentage of base absorbed decreases with the concentration of solution, being highest in the case of the weakest concentration and lowest in that of the greatest concentration, or the saturated solution. The amount of base

TABLE 4

Effect of temperature upon absorption

Ice Water vs. Room Temperature

NO.	SALT	CONCENTRATION OF SOLUTION USED (50 CC.)	CO_2 OBTAINED		BASE EQUIVALENT (ABSORBED)	
			At ice water temperature	At room temperature	At ice water temperature	At room temperature
			gm.	*gm.*	*gm.*	*gm.*
1	Na_2CO_3	0.04 *M*	0.00834	0.02252 (av. of 3)	0.01177	0.02973
2	Li_2CO_3	0.04 *M*	0.00884	0.02405 (av. of 2)	0.00602	0.01640

Hot Water Bath vs. Room Temperature

NO.	SALT	CONCENTRATION OF SOLUTION USED (50 CC.)	CO_2 OBTAINED		BASE EQUIVALENT (ABSORBED)	
			At water bath temperature	At room temperature	At water bath temperature	At room temperature
			gm.	*gm.*	*gm.*	*gm.*
1	Na_2CO_3	0.01 *M*	0.04240	0.01863	0.05975	0.02625
2		0.02 *M*	0.05368	0.02288	0.07564	0.03224
3		0.03 *M*	0.04078	0.02218	0.05746	0.03125
4		0.04 *M*	0.04150	0.02252	0.05848	0.02973
5		0.05 *M*	0.02376	0.02138	0.03348	0.03012
6		0.06 *M*	0.02526	0.01267	0.03559	0.01785
7	Li_2CO_3	0.04 *M*	0.05896	0.02405	0.04020	0.01640
8	$CaCO_3$	2.0 gm.	0.06378	0.03020	0.08131	0.03850

absorbed is variable, increasing from the weakest concentration until a certain definite concentration is reached which represents the maximum absorption. Beyond this point, which is probably different with different salt solutions, an increase in concentration results in a decrease in absorption. Saturated solutions show practically no absorption of base.

The effect of temperature upon absorption was obtained by placing the flasks containing 50 gms. of an unlimed soil and 50 cc. of carbonate solutions for 2 times into a mixture of snow and water and in water which had been heated to the temperature of the steam bath. The results are given in table 4.

The results given in table 4 substantiate more fully the statement made above, that the amount of absorption depends upon the degree of hydrolysis of the salt used, for hydrolytic action is increased with increase in temperature.

This difference in the hydrolysis of salts and the factors governing hydrolysis is thought to explain, largely, the different results obtained by the use of the various soil acidity methods.

EVIDENCES THAT THE DECOMPOSITION OF CARBONATE OF LIME BY SOILS IS DUE TO THE PRESENCE OF REACTIVE CHEMICAL CONSTITUENTS AND NOT TO SURFACE AREA

The following tests are offered as evidence that, in the absence of reactive chemical substances, surface area takes no part in the decomposition of calcium carbonate by soils. The method employed in making these tests as well as all following tests in which carbonates are used has been previously described.

Sand

The sand used in this instance was a representative sample of a large mass of sand which had been deposited upon the shore of the Connecticut River by current and wind action. It was selected as representative of the more resistant mineral constituents of the soils of the valley drained by the Connecticut River. After pulverization in a procelain mortar this soil had, with one exception, the physical appearance of the soils of the station plots. It was a little less highly colored. Upon shaking this finely powdered sand with water a turbidity resulted which was greater in comparison than the turbidity produced with the soils from the different plots; filtration was found to be more difficult, and the filtrate more cloudy. This sand showed a basic absorption which was equivalent to 0.00007 gm. $CaCO_3$ (1 gm. sand). Two million pounds of this finely pulverized sand would show a basic absorption equivalent to 140 lbs. $CaCO_3$.

Clay

Clay is usually mentioned as one of the best means of illustrating surface adsorption. There can be no question as to the fine state of division of the clay particles and the enormous surface area. The sample of clay used was of an exceptionally pure variety obtained on the shore of the Connecticut River from the bed of a brook. The water running over the surface of this clay was very clear and pure. The amount of carbon dioxide obtained, by several treatments of 50 gm. of clay and 1 gm. of precipitated chalk according to the method previously described, was so small that it may be considered negligible. The quantity expressed in terms of carbonate decomposed, however, was equivalent to 0.00002 gm. $CaCO_3$. Two million pounds of this clay would absorb an amount of base equivalent to approximately 40 pounds of $CaCO_3$.

A qualitative test made upon a sample of this clay showed, as expected, an abundance of iron and aluminum but no calcium. The iron and aluminum were present as complex silicates.

It is plainly evident from the results of this experiment that the enormous surface area of this clay had no adsorption influence upon the base of the carbonate.

As a further test for surface adsorption, pumice was tried. Pumice is a peculiar vasicular variety of feldspathic lava. It was ground very finely in a mortar and the basic adsorption as shown by test was very small. The amount of carbon dioxide obtained was 0.0000028 gm. for 1 gm. of pumice. This is equivalent to 0.000006+ gm. of $CaCO_3$. Two million pounds of this pulverized pumice, representing a very large surface area, would be capable of adsorbing an equivalent to only 12 pounds $CaCO_3$.

In consideration of all the above tests there seems to be some evidence indicating that surface area alone plays practically no part in the decomposition of calcium carbonate and on the other hand any observed decomposition of carbonate is the result of chemical action, brought about by the presence of weak acids or by other reactive chemical substances.

HYDRATED SILICA AND ALUMINA

It is believed that the rate and intensity of any possible reaction between the above colloidal substances and limestone must be extremely slight because of the chemical nature of the substances involved. Any slight reaction with lime is thought to be due to the formation of weak acids brought about by the very slight hydrolytic dissociation of the hydrated substances. The faintly acid character of the colloidal solutions of hydrated alumina and silica was shown by the appearance of a slight pink coloration upon application of methyl red as indicator in the hyrogen-ion concentration test.

It is plainly evident that the result of such a determination is entirely dependent upon the purity of the substances which are brought into contact with the limestone. With the above fact in mind great care was exercised in the preparation of the colloidal solutions. The hydrated alumina and silica were first precipitated from solution, transferred to Büchner funnels and well washed with distilled water. The gelatinous masses were then transferred to specially constructed dializers and the process of purification was continued for many months, after which the hydrated products were washed into large Erlenmeyer flasks. Washing by decantation was then resorted to and this operation was repeated until the colloid preparations showed by indicator tests no change in the slight hydrogen-ion concentration.

Approximately 20- and 30-cc. portions of the well-shaken gelatinous mixtures were taken for experimentation. One-half gram of precipitated chalk and a small amount of water were added to each flask and CO_2-free air was drawn through each flask for four hours.

It was found that 0.0025 gm. CO_2 in one case and 0.0014 gm. in the other resulted from the action of precipitated chalk upon hydrated alumina in the presence of water. With hydrated silica 0.0036 gm. CO_2 was obtained in each case. The experiment was continued the next day, without disconnecting the

flasks containing the hydrated products, and after running another four hours 0.0013 and 0.0012 gm. CO_2 was obtained with aluminum hydrate and 0.0014 and 0.0009 gm. CO_2 with the hydrated silica.

In view of the fact that the indicator test showed a slight acidity it is believed that the decomposition of the small amount of $CaCO_3$ was due to absorption of the base and not to adsorption.

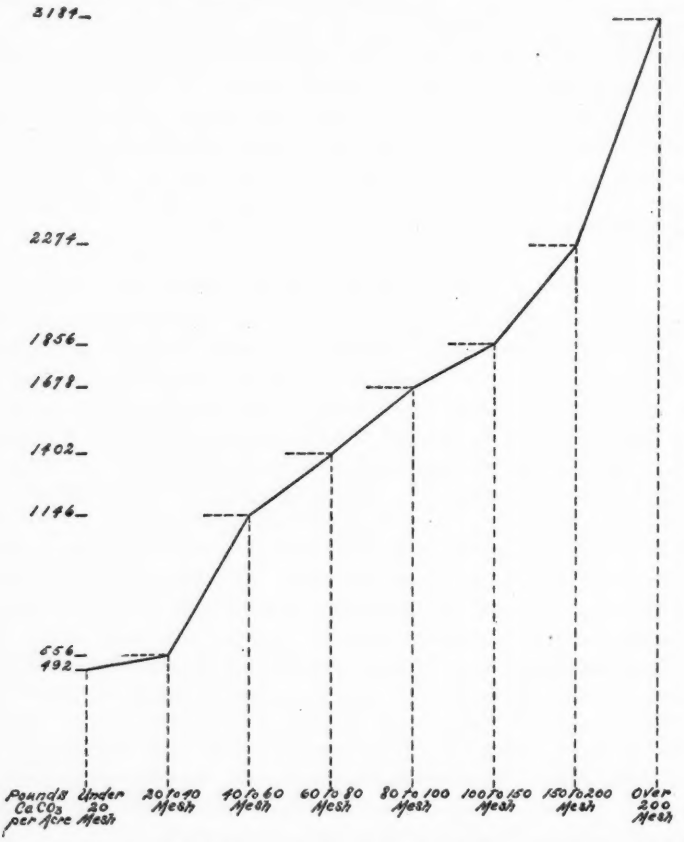


FIG. 1. GRAPH SHOWING THE DEGREE OR VELOCITY OF THE REACTION BETWEEN A SOIL AND CARBONATE OF LIME AS INFLUENCED BY THE FINENESS OF THE CARBONATE

RATE OF DECOMPOSITION OF $CaCO_3$, OR THE RATE OF ABSORPTION OF THE BASE, CaO

The rate of absorption of CaO is dependent upon the size of the $CaCO_3$ particles which are brought into contact with the moist soil and furthermore, which is self-evident, the rate is also dependent upon the mass of $CaCO_3$ up to a certain point.

The results in table 5 were obtained by the treatment of 50 gm. of an unlimed soil with 1 gm. of $CaCO_3$ of different sized particles[4] using the same general method.

The results obtained are in agreement with the old experiments of G. Stas, cited by Ostwald (1, p. 72) who found the solubility of silver chloride in the precipitated form (in other words, as particles of approximately colloid size) to be a hundred times greater than the solubility of this same substance when granular or coarsely dispersed. This behavior is not peculiar to silver chloride, but holds for all solid substances. It is also plainly evident that the velocity of the reaction between the soil and carbonate, measured in terms of carbon dioxide is in accord with Wenzel's law, which reads: "the reactive velocity of solids with liquids is proportional to the area of contact."

The data in table 5 with representative graph, figure 1, are of value for illustrating the availability of limestone of different degrees of fineness when applied to the soil. The fact that the rate of absorption is controlled largely

TABLE 5

Effect of fineness of $CaCO_3$ on the absorption of base

NO.	DEGREE OF FINENESS OF $CaCO_3$	CO_2 PER GRAM OF SOIL	$CaCO_3$ EQUIVALENT	REACTING $CaCO_3$ PER ACRE OF SOIL (2,000,000 LBS.)
		gm.	*gm.*	*lbs.*
1	Less than 20-mesh	0.000108	0.000246	492
2	Through 20-mesh	0.000122	0.000278	556
3	Through 40-mesh	0.000252	0.000573	1146
4	Through 60-mesh	0.000308	0.000701	1402
5	Through 80-mesh	0.000369	0.000839	1678
6	Through 100-mesh	0.000408	0.000928	1856
7	Through 150-mesh	0.000500	0.001137	2274
8	Through 200-mesh	0.000700	0.001592	3184

by the surface area of carbonate particles denotes that any appreciable decrease in the amount of carbonate used in the above tests would result in greater comparative differences. It is evident that a certain definite total surface area of particles is necessary to obtain a maximum absorption within a given time. Any increase in surface area beyond that required for maximum absorption will produce no acceleration in the rate of absorption, (table 6), but a decrease in the total surface area below the amount required to attain the maximum amount will result in a corresponding decrease in rate of reaction. The deduction is plain that if 0.5 or 0.25 gm. of $CaCO_3$ were used in place of the 1 gm. greater comparative differences in the rate of absorption would have been obtained.

The results in table 5 indicate the advisability of applying the finer grades of carbonate of lime to the soil whenever a quick response, in terms of a reduc-

[4] Different sized particles of $CaCO_3$ were obtained by grinding marble in a mortar and using sieves of different meshes.

tion of the hydrogen-ion concentration is desired or whenever a deleterious soil environment, due to the presence of excessive amounts of certain toxic salts, is to be remedied. With an increase in fineness of particles there results an increase in the degree of basic activity of the limestone, as measured in terms of velocity reaction. The rate of absorption of CaO would progressively increase until the carbonate was obtained in the finest condition possible, amorphous, approaching the colloid state.

It has been proved that different amounts of soluble carbonates greatly influenced the degree of absorption (table 3). It has also been proved that the rate of absorption is dependent upon the frequency of contact between soil and carbonate particles in a water medium (table 5). With these facts in mind an experiment was undertaken for the purpose of showing that varying amounts of $CaCO_3$, in a very fine state of division, produce no changes in the rate of absorption, provided the carbonate is present in excess of the amount actually required to complete the reaction. Fifty grams of an unlimed soil was treated in the usual way with 0.25, 0.50 and 1.00 gm. of precipitated chalk. The

TABLE 6

Relation of different amounts of precipitated $CaCO_3$ to absorption

$CaCO_3$	CO_2 1 GM. SOIL	$CaCO_3$ EQUIVALENT 1 GM. SOIL	REACTING $CaCO_3$ PER ACRE (2,000,000 LB. SOIL)	$CaCO_3$ EQUIVALENT PER ACRE APPLIED (2,000,000 LB. SOIL)
gm.	*gm.*	*gm.*	*lbs.*	*tons*
0.25	0.000633	0.00144	2880	5
0.50	0.000619	0.00141	2820	10
1.00	0.000623	0.00142	2840	20

quantities of $CaCO_3$ used are equivalent to the application of 5, 10 and 20 tons of limestone per acre basis (2,000,000 pounds of soil).

The results given in table 6 plainly show that the different amounts of $CaCO_3$ used had no effect upon the degree of base absorption. This is because the solubility of calcium carbonate is very small and the maximum solubility is easily reached by a small amount of calcium carbonate. It must be borne in mind, however, that 100 per cent base absorption is very likely an impossibility and therefore the amount of base present must be many times greater than the amount of base that is capable of being absorbed. In case of substances which have a low solubility product consideration must be taken of the fact that the rate of action is to a large extent dependent upon the surface area and the number of particles which come into contact with the absorbing material.

OTHER ABSORPTION EXPERIMENTS

Experiments were carried out for the purpose of ascertaining whether or not a soil, after having absorbed a quantity of base which was considered a maximum amount, was capable of showing further basic absorption.

The absorption of base was obtained in the usual manner. The soil to which water and calcium carbonate had been added was transferred to a Hirsch funnel and filtered and washed with distilled water. After a long and thorough washing the soil was removed from the filter and dried at room temperature. After it was well dried a second absorption test was made in the same way after the addition of more precipitated chalk. The amount of carbon dioxide obtained was very slight, indicating that the soil had previously absorbed a maximum amount or very nearly this quantity of base. The small amount of carbon dioxide obtained in this second instance might be laid to some cause other than a reaction between soil and carbonate, as absorption of carbon dioxide from the atmosphere and carbon dioxide from bacteria activity. This laboratory experiment agrees with the result obtained in case of soil 5, table 7.

Other experiments were made to determine the base absorbing power of soils which had previously been treated or digested with hydrochloric acid. It was found that after removing all lime from the soil, the basic absorption was increased, the increase depending upon the amount of lime which had been added to the soil in the field.

Fifty grams of 100-mesh soil, taken from fertilizer experiment plots, were treated with 0.5 gm. of precipitated $CaCO_3$ and the absorption values were obtained in the usual way (results given in table 7). After completing this test the soil was filtered through a Hirsch funnel and thoroughly washed. This filtrate was saved. The soil was then transferred to an Erlenmeyer flask and an excess of dilute hydrochloric acid was added. The digestion was either hot or cold. After several hours digestion the soil was again transferred to a Hirsch funnel and filtered and washed until there resulted a constant hydrogen-ion concentration, as shown by use of indicator. (It was found that a soil exhibited two phases of acidity, which might be termed active and potential acidity.) The soil was then dried at room temperature and afterwards the absorption test was again made. Results are given in table 7. The soil was again filtered and this filtrate was added to the first.

The filtrate from each absorption test was evaporated to dryness. The resulting residue was of appreciable quantity, light colored and of low specific gravity. This residue upon analysis was found to contain K_2O and P_2O_5. This test seems to indicate that lime has a replacement power and that K_2O and P_2O_5 are made available.

The results given in table 7 clearly prove that a soil after acid treatment and after all traces of the acid have been removed, is capable of greater basic absorption. This absorption was increased three to four times in all cases but one. The exception was soil 5, taken from a lime plot, and the absorption in this case amounted to an increase of about twenty-five times.

The effect of continuing the acid-followed-by-lime treatment upon the absorbing material contained in the soil was determined by subjecting a number of the same samples of soils used, 1, 2, 3, 4, to a second acid treatment and the amount of base absorbed aga in determined. The difference in absorption of CaO, per gram of soil, amounted to 0.00037, 0.00045, 0.00045 and 0.00048 gm. respectively. It is seen from these results that a continuation of such a treatment decreases the absorbing power of a soil but slightly. Large amounts of both iron and aluminum were removed from the soil by acid digestion and

yet the absorption of CaO still persisted. The slight decrease in the degree of base absorption may be accounted for in either of two ways. First, each digestion of soil with acid may be destructive to a slight degree to the absorbing material, and second, the absorbing material reacting with lime may be rendered slightly soluble and so is thus removed, in small quantities, from the soil.

It was further noted that the total basic absorption (after acid treatment) in terms of calcium oxide was approximately equal to the initial absorption (made on the original soil) plus the CaO (in the original soil). This would indicate that the CaO absorption is dependent upon the amount of calcium already in combination in the soil. The result obtained in case of soil 5 (lime plot) substantiates this statement.

TABLE 7

Absorption of CaO by soil before and after treatment with HCl

SOIL	CO_2 BASIS		$CaCO_3$ BASIS		REACTING $CaCO_3$ ACRE BASIS 2,000,000 LB. SOIL	
	Before	After	Before	After	Before	After
	gm.	*gm.*	*gm.*	*gm.*	*lbs.*	*lbs.*
1	0.0003230	0.0014545	0.0007344	0.0033070	1469	6614
2	0.0003289	0.0015016	0.0007479	0.0034141	1496	6828
3	0.0003098	0.0014917	0.0007044	0.0033917	1409	6783
4	0.0004103	0.0017893	0.0009331	0.0040683	1866	8137
5	0.0000618	0.0015840	0.0001406	0.0036016	281	7203
6	0.0002334	0.0012899	0.0005308	0.0029342	1062	5868
7	0.0004488	0.0019338	0.0010206	0.0043968	2041	8794
10	0.0004941	0.0019409	0.0011237	0.0044130	2247	8826
11	0.0005144	0.0023028	0.0011697	0.0052360	2339	10472
12	0.0004752	0.0019965	0.0010807	0.0045395	2161	9079
13	0.0003980	0.0017575	0.0009050	0.0039961	1810	7992
14	0.0004156	0.0018788	0.0009451	0.0042720	1890	8544

INFLUENCE OF SOLUBLE SALTS UPON THE ABSORPTION OF BASE

That the presence of soluble salts in the soil influences lime absorption can be easily demonstrated by laboratory experiments carried out in the same manner as the preceding absorption tests. To 50 gm. of two unlimed soils was added 1 gm. of C.P. salts in one case and 1 to 2 gm. of commercial salts in the other. All tests were carried out for a period of three hours with results shown in table 8.

The results given in table 8 clearly indicate that the degree of absorption as exerted by the presence of other salts depends largely upon their chemical nature, and the subsequent decomposition of $CaCO_3$, may range from a very small to a large amount. The differences in absorption are very striking in those cases in which $(NH_4)_2\,SO_4$, $FeSO_4$, and calcium cyanamide are used. It is very clear that a reaction took place between the $(NH_4)_2\,SO_4$ and $CaCO_3$,

and $FeSO_4$ and $CaCO_3$. It is also evident upon consulting numbers 4, 7, and 12 that the soil was a factor in increasing the rate of decomposition of carbonate. The low absorption obtained when calcium cyanamide was used is thought to be due to the greater degree of hydrolysis of calcium cyanamide rather than the carbonate. The fact that the cyanamide and carbonate both contain like ions (Ca) might be given as a cause for the low absorption, but preference is given to the former theory.

The action of calcium carbonate upon soluble salts of aluminum and manganese was also illustrated. To a solution of the sulfates of aluminum and manganese, calcium carbonate was added. The mixtures were shaken and allowed to stand for some time. The results obtained clearly showed that

TABLE 8

Absorption of CaO in the Presence of other salts

NO.	PRECIPITATED CHALK	SALT USED	CO_2 OBTAINED
	gm.		*gm.*
Soil A			
1	1	$CaSO_4$	0.01467
2	1	$MgSO_4$	0.02141
3	1	Na_2SO_4	0.01483
4	1	$(NH_4)_2\ SO_4$	0.02937
5	1	$FeSO_4$	0.06805
6	1		0.01324
Soil B			
7	0.5	1 gm. $(NH_4)_2\ SO_4$	0.03012
8	0.5	2 gm. acid phosphate	0.01481 *
9	0.5	2 gm. acid phosphate and 2 gm. calcium cyanamide	0.00024
10	0.5	2 gm. calcium cyanamide	0.00021
11	0.5		0.01559†
No soil			
12	0.5	1 gm. $(NH_4)_2\ SO_4$	0.00722

* Average of two.

† Average of three.

aluminum was precipitated as $Al(OH)_3$ and the manganese as a brown oxide, probably as Mn_3O_4, or a basic oxide. The aluminum was precipitated quite readily whereas a much longer time was required to remove the manganese from solution, as oxygen is necessary to bring about the latter reaction. The experimental evidences obtained by the above tests are of help in explaining the reason why absorption tests in general are unreliable in the sense of expressing the lime requirement of a soil.

DISCUSSION OF RESULTS

It is not assumed that the amount of calcium absorbed, as shown by this method, expresses numerically the number of pounds of calcium carbonate that

should be applied per acre of soil and consequently construed as an exact lime requirement method. In general, however, a large absorption indicates that the soil so tested is deficient in lime for the normal and optimum growth of crops which are dependent upon this basic element either as a direct plant food or to give the proper reaction for plant development. A soil that has received a dressing of lime may show by the absorption test that it is capable of absorbing still more lime, and yet there may be present a sufficient amount of lime to satisfy the physiological needs of the plant, and also to act as a soil corrective.

The absorptive capacity of a soil for lime is influenced by previous lime and fertilizer treatment and consequently is less than the total basic absorptive power of the soil. This point is well illustrated in case of soil 5 which during the years 1899 to 1919 had received nothing but a yearly application of lime together with additional amounts upon the several occasions when the whole field was limed. Manure and a commercial fertilizer consisting of a mixture of barium sulfide and apatite were added in 1919, and in 1921 manure alone was added. The absorption test made upon a sample of this soil, collected in 1921, showed so slight a basic absorption that it was a question of whether or not the results obtained were due to basic absorption or to occluded carbon dioxide in the soil, the source of the latter probably being bacterial. (See table 7.) The results obtained would indicate that this soil had very little lime-absorbing power, but the reason for the very small degree of absorption noted is plainly apparent upon consideration of the total amount of lime which has been added to the soil of this plot.

The amount of residual $CaCO_3$ determined in this soil approximated 3000 pound per acre (method of Assoc Off. Agr. Chem.). The results of both tests clearly prove that this soil had absorbed lime to its utmost capacity.

The causes of a high lime absorption shown by some soils are:

1. The presence of a large amount of humic substances in the soil (humic compounds and acids) which are very reactive with lime.
2. A high hydrogen-ion concentration resulting from the presence of acids, principally organic and carbonic, and acid salts, such as sulfates of the weakly basic elements, ferrous, ferric, and aluminum sulfates.

whereas a low lime absorption denotes the following:

1. A very poor and unproductive soil deficient in humus, like sand and clay.
2. A soil containing a sufficiency or superabundance of lime (as calcium humates and carbonates).

SUMMARY

The colloids present in soils may be conveniently divided into two classes, inorganic and organic. The forms commonly comprising the class of inorganic colloids are silicic acid and the silicates, aluminum hydroxide and its compounds with silicic acid and iron hydroxide. The different kinds included in the organic class of colloids are the humic compounds and the various kinds of

microörganisms, like the soil bacteria and fungi and the mucinous substances which are secreted by such organisms.

Colloids are capable of showing adsorption and absorption. Adsorption, which is a surface area phenomenon, is believed to be very small, whereas absorption, which might be termed adsorption-decomposition, or in plain terms, a physico-chemical reaction, is quite large, depending upon the chemical nature of the reactive colloids.

The absorption of bases by soils is directly dependent upon the degree of hydrolysis of the salt in solution. The laws governing hydrolysis therefore would apply to absorption, namely: chemical constitution of the salt, concentration and temperature.

The absorption of bases of compounds containing a highly ionized base and acid is small. A decrease in the ionization of both base and acid results in an increase in the degree of hydrolysis and consequently an increase in base absorption.

The absorption of the base of substances which have a small solubility product is in accordance with Wenzel's law: the reactive velocity of solids with liquids is proportional to the area of contact.

CONCLUSIONS

The absorption of bases by a soil is due to chemical reactions between soil constituents and the dissolved salt. Adsorption or surface attraction of colloids is only an accessory. These facts have been shown by the measurement of the CO_2 released by the reactions.

REFERENCES

(1) OSTWALD, W. 1917 Theoretical and Applied Colloid Chemistry, *Trans. by* Fischer, W. H., first ed., p. 151–152. Blakiston's Sons & Co., Philadelphia.

(2) TAYLOR, W. W. 1915 Chemistry of Colloids, p. 292. Longmans, Green & Co., New York.